1

HIGHWAY RESEARCH RECORD

Number 1

Materials Inventories

7 Reports

HIGHWAY RESEARCH BOARD
OF THE
NATIONAL ACADEMY OF SCIENCES —
NATIONAL RESEARCH COUNCIL
publication 1064

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Presented at the
42nd ANNUAL MEETING
January 7-11, 1963

HIGHWAY RESEARCH BOARD
of the
Division of Engineering and Industrial Research
National Academy of Sciences—
National Research Council
Washington, D. C.
1963

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Introduction

PRESTON C. SMITH, Chief, Soils, Foundations and Flexible Pavement Branch, U. S. Bureau of Public Roads

•THE EXPANSION in highway construction and the increased demand for high-quality construction aggregates have made more State highway departments aware of the need for comprehensive materials inventories. The inventory makes information available that (a) permits location and design engineers to fit the location and design of the highway structure to the economically available materials, (b) permits the contractor to make a more realistic bid on the proposed construction, (c) aids the soils and materials engineers in locating sources of suitable materials for the specific highway structure and for subsequent maintenance needs, and (d) promotes the conservation of high-quality aggregates for structures requiring this specific type of material.

Comprehensive materials inventories were made in Maine, Michigan and New Hampshire more than 30 years ago, and similar inventories were subsequently made in several other States. The highway departments in these States have learned that, to be of maximum value, the inventory of available aggregate materials must be kept up-to-date.

E. A. Finney, in the Foreword of Highway Research Board Bulletin 62 (1952), summarized some of the information obtained in a 1948 questionnaire by the Committee on Materials Surveys, Department of Materials and Construction, to the State highway departments. He reported, "Only four states have actually done work using well-known geophysical methods for material surveys and only two states have experience in air-photo methods." His committee sponsored a symposium at the 1952 Annual Meeting, to acquaint materials engineers with various means of procuring and presenting information regarding natural materials sources. The symposium papers were published in Highway Research Board Bulletin 62.

A survey by the Bureau of Public Roads in 1957 showed that 26 State highway departments had made or were making an inventory of highway materials, and that 18 States were interested in making a materials inventory. Seventeen State highway departments are either currently using 1½ percent Federal-aid funds for these inventories or have completed such an inventory in their planning and research programs.

The Committee on Surveying, Mapping and Classification of Soils, of the Department of Soils, Geology and Foundations, decided in 1962 that, because of the inquiries received by the Bureau of Public Roads and several State highway departments for information regarding procedures or methodology for materials inventories, a second symposium on the subject should be arranged. Each State highway department was requested to submit (a) a brief description of its method of making a materials inventory for a considerable portion or all of the State, (b) a discussion of the use made of the information, and (c) an example of a materials map. From these submissions, the Committee selected six State highway departments to prepare papers that would give a cross-section of current materials inventory procedures. Geographic location of the six States is such that a variety of geologic origins of construction materials are represented.

The 1963 symposium papers show that the office sources of information and the field methods described in the 1952 symposium papers are being utilized. However, some State highway departments are handicapped by a lack of adequately trained personnel in aerial photographic interpretation and geophysical methods of materials searches.

The 1963 symposium papers also show a variety of ways in which the inventory data and potential sources of materials may be presented.

Although only limited materials inventory cost data are presented, it is probable that most of the State highway departments that have made such inventories have decided

that it was a good investment. The presented papers should be particularly valuable to those highway departments that are contemplating making a comprehensive materials inventory or have just started one.

Inventory of Construction Aggregate Sources in Michigan

J. C. BREHLER, Engineer of Materials, Michigan State Highway Department

This paper presents the method used by the Michigan State Highway Department in compiling, for ready reference, information pertaining to test data on existing construction aggregate sources. It describes the format and defines, in detail, the meaning intent of the various column headings used in presenting the available data. It also describes briefly the geological origin of the natural gravel deposits found in the State and its resultant effect on the aggregate quality.

•THE Michigan State Highway Department's "Inventory of Construction Aggregate Sources" was initiated primarily in order that information pertaining to existing test data would be readily available to contractors and producers on short notice.

In 1938, Michigan's trunkline system was comprised mainly of gravel surfaced roads which required what was considered in those days to be large productions of surfacing gravels for construction and maintenance. As more deposits were opened, the need was recognized for a systematized means of record keeping, other than searching through the individual project files for test data.

The sand and gravel sources in Michigan (1) are the results of the glacial drift depositions formed by the successive advances and recessions of the Wisconsin Glacier, the last of the glaciers which at one time had covered the entire State. In these drift deposits are found areas of unstratified debris as caused by the melting action of the glacier and the amount and character of debris held in the ice. These areas vary in thickness from only a few inches in the Alpena area in the northeastern part of the Lower Peninsula to approximately 1,200 ft in the Cadillac area which is located in the northwestern part of the Lower Peninsula.

The features formed by the drift deposition in the recession of the Wisconsin Ice Sheet vary from flat level lake beds to a very rough terrain of ridges, or moraines. The material from these formations varies from clay to gravel and the granular textures may be segregated or mixed heterogeneously with boulder clays.

As would then be expected, the complexity of the gravel features resulting from these glacial drift deposits is such that considerable variations can be expected even within a single deposit. In Michigan it is not uncommon to identify schists, shales, ochres, cherts, iron clay stones, and igneous rocks in a product from a single deposit.

In the original Inventory it is estimated that some 500 sources were listed with pertinent data. In the majority of instances, these were sources from which surfacing aggregates had been produced; and, in a few instances, locations where traces of gravel had been encountered by the soils engineers in the borings of the soil surveys for construction projects.

The original Inventory was introduced primarily for Departmental use and contained the name of the property owner, or the pit name, the county in which it was located, the pit number in the county, the legal description of the property, the driving directions from the nearest town, and test data, in chronological order, pertaining to abrasion results, soft stone, and crushed particle, contents, and the fraction passing the No. 200 sieve which had been obtained from the samples of either bank run or processed gravel,

Paper sponsored by Committee on Surveying, Mapping and Classification of Soils.

which had been submitted to the Laboratory. Later, county maps were added to the original format, on which the locations of the pits were marked and identified by the pit number.

As expressed earlier, the use of this Inventory was almost exclusively by the Department as a ready reference of current test data, and the pit locations where the aggregate inspectors were to report when assigned. However, as more and more data were accumulated and incorporated with the existing information, gravel producers began making inquiries regarding potential sources in areas in which they were not too familiar and in which they were contemplating the submission of a contract bid on a proposed construction project. As the contractors became more familiar with the existence of such compiled information, requests were received for copies and Departmental approval was given to make the current issues available to the contractors, gravel producers, other State agencies and those who were connected with the highway construction industry. Gravel producers, particularly, on many occasions have expressed the opinion that much time and many miles of driving can be saved through a review of the available information compiled in the Inventory pertaining to areas in which they are interested at a particular time.

This information is also used on occasions when a new deposit is being exploited. In these instances, test results of established deposits in the area are reviewed, and based on this review a considered opinion is expressed to the producer as to whether material produced from the new deposit could be expected to meet the specification abrasion requirements. Knowing how variable the deposits can be even with a small area this opinion is no more than an educated guess, however, and the producer is advised of this and is aware of the calculated risks involved.

The Inventory also includes information regarding stone quarries, commercial gravel plants, several waste mine rock and stamp sand stockpiles, a blast furnace slag plant, and undeveloped gravel deposits, as well as the gravel pits from which material has been used.

About ten years ago an investigation was started on a limited scale to determine the possibilities of further augmenting the information given in the Inventory by compiling a production history of the individual deposits. Of primary interest were the difficulties encountered by the producer in the production of a specification aggregate, such as excessive sand which required the use of sand ejection equipment, heavy overburden which required more than a normal amount of stripping, etc. These observations were submitted by the inspectors after completion of the production of the contract commitments from a specific pit for a particular project. The results showed that the majority of the deposits were so variable in character that a consistent pattern could not be established. On this basis, it was felt that such information could be misleading or misinterpreted by the producer if incorporated in the inventory and so the investigation was discontinued.

In detail, the pages of the gravel pit data are arranged according to the alphabetical order of the county names, of which there are 83 in Michigan. In each county group, the pits are arranged in numerical order in the first column of each page of inventory data together with the name by which it is identified. A typical gravel pit data sheet is shown as Appendix A. In cases where the ownership of a pit has changed, or where for some reason the name of the pit has been changed from that carried in previous editions, the current name is given first with the previous or alternate name below it. Each pit is located by number on the accompanying map of the county. A typical county map showing pit locations is shown as Appendix B.

Under the heading "Pit Location and Direction Data" is given the legal description of the location of the aggregate source, i.e., the quarter-quarter-section, section number, townline, and range. The road mileage and direction from some established reference point to the aggregate source are also included under this heading. As relocations of trunklines are completed, the directions referring to those trunklines are revised and corrected in subsequent editions.

Under "Laboratory Test Number" the first two digits indicate the year in which the test was made and are followed by the test number assigned. The values in the column headed by "Abrasion Test Result" represent the percent of wear obtained on the sample

by Deval "D" abrasion test, AASHO method: T-4, unless otherwise designated. Deval A, B, C, or E abrasion tests are designated by the addition of the respective letter to the percent of wear figure. The addition of the letters AL, BL, CL, or DL to the percent of wear figure indicates that the material has been tested by the Los Angeles abrasion test method, AASHO method: T-96. In both the Deval and the Los Angeles abrasion test results the letters A, B, C, and D refer to the gradation of the sample tested, which usually depends on the intended use of the aggregate. In the column headed "Crushed" is given the percent of crushed aggregate particles in the Deval abrasion test sample. This is related to the percent of wear value obtained in the Deval abrasion test in that for each ten percent of crushed particles in the aggregate, an additional one percent of wear is allowed above the maximum specification allowance for uncrushed bank-run material. The Los Angeles abrasion test results are interpreted independent of the percentage of crushed particles in the aggregate; therefore, no figures are ordinarily given for crushed material in samples tested by the Los Angeles abrasion test method.

In the column headed "Soft and Non-Durable" the percent of soft and non-durable particles in the test sample is given. Under the heading "#200" is listed the quantity (in percent) of the fraction passing the number 200 mesh sieve in the test sample as determined by the AASHO method: T-27.

Throughout the Inventory a number of abbreviations are used in order to conserve space. To assure a clear interpretation of the data given, a list of all abbreviations used in the book with the translation as intended by the Office of Testing and Research is also made part of the publication.

The latest edition was printed in 1959 and contains information pertaining to more than 2,500 aggregate sources throughout Michigan. The Departmental office copy of this edition contains up-to-date information regarding the old deposits, and the new deposits which have been opened up since the last printing. All of this will be incorporated in the next edition.

In conclusion, in order than any misunderstanding or misinterpretation of the data contained may be avoided the following statement is emphasized on the first page of each edition:

> It must be thoroughly understood, however, that all test results given in this inventory are based on material already removed from the listed sources and do not guarantee in any way that sizeable amounts of the same material remain for future use. Neither should the test data be construed as always representing material remaining in the pit. Due to glacial action over Michigan's entire surface, it is generally found that natural gravel deposits vary considerably within small limits of area. It is imperative, therefore that this inventory be used only as a guide in conjunction with visual inspection of pits and not as a material survey report.

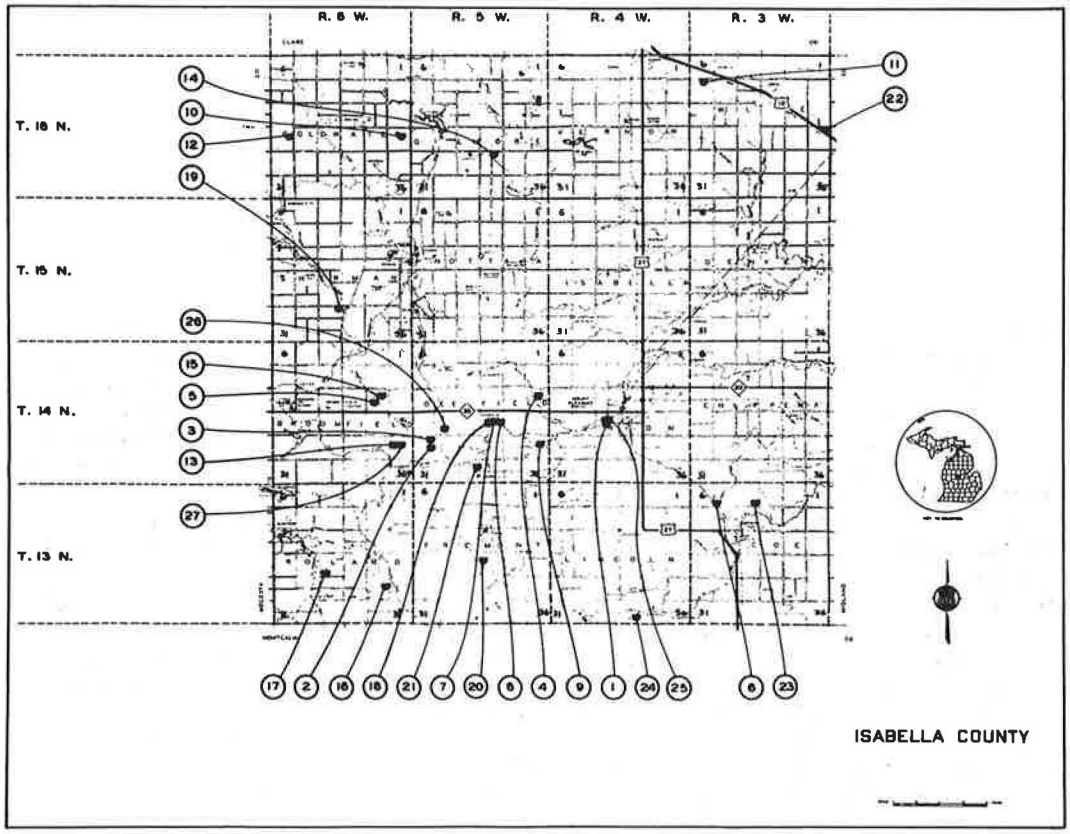
REFERENCE

1. Leverett, F., and Taylor, F., "The Pleistocene of Indiana and Michigan and the History of the Great Lakes." United States Geological Survey (1915).

Appendix A

No.	Name	Pit Location & Direction Data	Lab. No.	Abr.	Cr.	SND	#200
1	McManaman, James	NE of SW Sec. 21 14N 4W 1 mi. S on US-27 from S junct. with M20, 1.6 mi. W on Co. Rd. & 0.3 mi. to N of Rd.	41-1515	17	16	0.8	1.7
2	Rife #1	NE of SE Sec. 30 14N 5W 9 mi. W on M20 from S junct. with US-27, 1.6 mi. S on Co. Rd. & to W of Rd.	37-1991 38-784	12 10	45 0	1.4 1.4	13.6 -
3	Rife #2	NE of NE Sec. 30 14N 5W 9 mi. W on M20 from S junct. with US-27, 1.1 mi. S on Co. Rd. & 0.1 mi. to W of Rd.	38-989 39-4881 40-1168	15 6 12	0 0 44	1.8 1.0 1.4	- - -
4	Zelen	SW of NE Sec. 13 14N 5W 4 mi. W on M20 from S junct. with US-27, 0.5 mi. N on Co. Rd., 0.5 mi. W & to N of Rd.	47-3239 48-2904	13 10	44 0	4.0 1.2	- -
5	Yost, L.	NE of SW Sec. 14 14N 6W 4.4 mi. E on M20 from Mecosta-Isabella Co. line, 0.45 mi. N on Co. Rd. & 0.15 mi. W on trail.	38-4664 38-4864 40-2895	10 15 12	0 81 65	0.6 4.3 0.6	- 9.9 6.3
6	Cernek Bros. (Mizer, W.)	SW of SW Sec. 5 13N 3W 0.5 mi. W on Co. Rd. & US-27 from R. R. in Shepard, 1.3 mi. N on Co. Rd. & to E of Rd.	48-3968 49-3862 51-4020	15 18 16	51 47 32	2.0 3.0 2.4	4.8 6.3 8.0
7	Hubscher, Geo. & Sons #3 (Russell Dersna) (Dedie, E. C.) (Quinlan, R. J.)	S 1/2 of NE & SE of NW Sec. 22 14N 5W Commercial hydraulic plant. 6.3 mi. W on M20 from S junct. with US-27, & 0.3 mi. to S of Rd.	36-1211 38-3896 41-4722 51-2209 57-3261	4B 4B 14 26AL 26A	5 7 0 - -	0.5 6.3 2.2 0.9 -	0.3 0.5 - 0.3 -
8							
9	Hubscher, Geo. & Sons #1	SW of NE Sec. 25 14N 5W 4.1 mi. W on M20 from S junct. with US-27, 1 mi. S on Co. Rd., 0.45 mi. W & 0.55 mi. S on lane.	47-2881	11B	22	1.7	0.4
10	Kripa, Mrs. Helen	SW of NE Sec. 24 16N 6W 5.4 mi. N on Co. Rd. from center of Weidman & 0.4 mi. W on lane.	48-3755 48-3844	11 14	0 58	2.6 2.8	- 7.7

Appendix B


R. 6 W.
R. 5 W.
R. 4 W.
R. 3 W.
T. 16 N.
T. 15 N.
T. 14 N.
T. 13 N.
14
10
12
19
20
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17
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8
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23
ISABELLA COUNTY

Surveys for Potential Sources of Aggregates

R. F. ROBINSON, Geologist, State Highway Commission of Wisconsin

Surveys for potential sources of aggregates have been an important aspect of the highway program in Wisconsin for more than 40 years. The surveys have become increasingly important in recent years because of a rapidly diminishing supply of acceptable aggregates in areas of former abundance, and the large volumes of aggregates required for highways of interstate standards.

The basic purpose of such surveys is to provide savings in the cost of transporting aggregates to the project.

• EXCEPT for the southwest quarter of Wisconsin, known as the Driftless Area, the entire State has been glaciated. The Driftless Area contains a few valley trains which in places provide sources of aggregates; however, the bulk of the aggregate deposits comes from sandstone and dolomite bedrock formations. Within the glaciated area gravel deposits provide the main source of aggregates. In some localities within the glaciated area, however, dolomitic bedrock, when it lies near the surface, may supply the main local source of aggregate.

It was recognized early in the history of the Commission that substantial savings could be made by using aggregate deposits on or near current highway projects as opposed to shipping in commercially produced materials. Although it is not always possible to find aggregate deposits of suitable quality on or near to the project, the Commission felt it worthwhile to instigate a program of exploration for aggregate deposits in areas within economical truck-haul distance of proposed projects. By mutual agreement between the Commission and the State Geologist, an annual program of aggregate surveys was begun in 1919 and continued up to the present time.

Exploration originally was confined to each side of the proposed project for a distance equal to that of the nearest railroad station. Searches now are extended to include the nearest productive area, or the nearest area of potential geologic structure.

PROCEDURE

The program of surveys for potential sources of aggregates is initiated annually when the Commission's Engineer of Materials requests information from the District Engineers as to proposed projects for which aggregate source information is required. Normally the surveys are performed at least three years prior to the anticipated date of construction. Information requested includes the project location and approximate mileage as well as the type and amount of material needed.

Following a tabulation of the Districts' information and Commission approval, a request for the next summer's survey requirements is forwarded to the State Geologist. On receipt of the request he makes arrangements for hiring the necessary personnel and proceeds with plans for conducting the surveys. The preliminary phases of preparation include organization and instruction of the survey parties and geologic studies.

Each survey party is composed of one party chief and two assistants. The party chief is a graduate geologist usually with previous field experience, and the assistants are undergraduate geology students. The party chief is directly responsible to the State Geologist for carrying out and completing the field work to the mutual satisfaction of the State Geologist and the Commission.

The geologic studies consist of gathering and examining all geologic data in the area of the specific projects. These data may consist of previous geologic notes, geologic and topographic maps, aerial photographs, well records or soil maps. Examination of

Paper sponsored by Committee on Surveying, Mapping and Classification of Soils.

Shawano CO. REPORT NO. 1317 LOCATION NO. 188

DATE 8/6/49 GEOLOGIST Wright

The NE ¼ of the NE ¼ of Sec. 32 Tp. 25N R. 17E

Undeveloped Quarry Site:

This site is located in the SE part of a flat-topped ridge underlain by dolomite of the Lower Magnesian formation. The thickness of the deposit is 30 feet but only 12 feet of vertical thickness is exposed. The rock is fairly hard, crystalline, gray, dense dolomite. Some chert was noted in a thin bed but it should not affect the quality of the material. Stripping varies from 0 to 4 feet. Estimated vardage 200,000 cubic yards. This location is recommended as a possible source of aggregate for concrete and bituminous pavements.

Shawano CO. REPORT NO. 1608 LOCATION NO. 221

DATE 7/18/62 GEOLOGIST Lamb

The NW ¼ of the NE ¼ of Sec. 20 Tp. 26N R. 16E

Gravel Pit and Undeveloped Location:

This deposit has had about 800 cubic yards of material removed. Drilling information has established that an additional prospect 200 yds. by 60 yds. by 3 yds. totalling 36,000 cubic yards is located to the east of the pit. The gravel is variable in size ranging from 1/4 inch to 5 inches with sand content diminishing eastward. The deposit appears to be outwash extending from a kame complex to the west. The material is recommended for bituminous and concrete aggregates.

Figure 1. Typical location reviews.

Shawano CO. REPORT NO. 1256 LOCATION NO.

DATE 7/27/46 GEOLOGIST Erickson

The SW ¼ of the NW ¼ of Sec. 22 Tp. 25N R. 17E

Sand Deposit, Negative Note

A small local sand deposit which appears at the surface on the N side of a drumlin-like hill in terminal moraine area was investigated. The deposit is .4 mi. S of the NW corner of sec. 22, To. 25N, R. 17E.

The material present is clean white coarse-grained sand which is present only as a small pocket 10'x10' at this point. The stripping proved to be too thick on all sides of the pocket to warrant use of the material. It is reported that the same sand outcrops on the south side of the hill where it was uncovered by a basement excavation. However a road cut through the drumlin-like hill shows a minimum stripping of 15' at the crest.

For this reason this deposit is not recommended for consideration for use as ballast on the STH 47 project.

Figure 2. Negative geologic note.

all the data may reveal certain areas which were not previously studied, areas of complex geologic structure which need further field investigation or general areas to resurvey.

FIELD WORK

Survey work in the field is begun by reviewing cuts, open pits and quarries in the vicinity of the project in order to evaluate known deposits as well as to familiarize the party personnel with the areal geology.

After the review of known deposits and exposures is completed, the survey party proceeds with examination of any new undeveloped potential sources brought to light by the field investigations or as extrapolated from the geologic studies. A power auger is usually available at this time to prove out and determine the extent of the suspected sources.

REPORTS

All investigated deposits or sites are written up in a report by the chief of the survey party (Fig. 1). Each location for a specific county is assigned a number from one on up and located by quarter section, township and range. Each location is then discussed with relation to the specific project for which the material has been investigated. Among the more important items discussed are type of deposit (such as outwash, esker, or kame), depth and nature of stripping, estimated yardage, length of haul to the project and for what use the material is best suited.

In addition to the described locations, negative geologic notes are submitted with the project report (Fig. 2). These notes pertain to sites that would not normally produce acceptable aggregates but appear by topographic form or other evidence to be worth investigating. The notes describe the general geology of the area and give locations of specific sites that were investigated with either test pits or auger holes. The notes provide good background for soils and detailed geologic studies of an area and help eliminate many sites from consideration during future investigations.

MAP PREPARATION

When the reports are completed they are forwarded to the Materials Section of the Highway Commission. Each location is plotted on a master county map at a scale of ½ in. = 1 mi. Such data as the type of deposit (outwash, esker or rock formation), its nature (either a pit or a quarry), and the approximate yardage are indicated by a series of symbols and abbreviations. Also, each site described by a geologic or negative note is plotted in its approximate location and labeled with an identifying symbol. Figure 3 is a reproduction of the symbol sheet.

The main idea in the map preparation is to represent all the data possible and indicate on a single map all investigated locations or areas that have a geologic description of any sort.

Recently with more intensive subsurface investigation, another series of symbols has been developed to indicate the location of auger holes. It is felt that this type of information should be represented separately so that subsurface data can be easily isoloated if needed.

After the maps are revised to include the most recent survey information, prints are prepared and distributed with the reports to the District Office concerned and the highway commissioner of the county in which the survey was conducted. Figure 4 shows a portion of a material survey map.

DEPARTMENTAL ACTIVITIES

At the present time some limited activities relative to surveys for aggregates are performed by personnel within the Materials Section of the Commission. Activities of this type are usually prompted by requests for supplemental aggregate information from the District Offices. These surveys may be made for a specific area adjacent to the proposed project or over a large area of a county where no known sources of

SYMBOLS & TYPES OF GLACIAL DEPOSITS		TYPES OF BEDROCK		NAMES OF ROCK FORMATIONS	
⚒	GRAVEL PIT-DEVELOPED	Ls	LIMESTONE	P€	PRE-CAMBRIAN IGNEOUS, METAMORPHIC & SEDIMENTARY ROCKS
X	PROSPECT-UNDEVELOPED	Ss	SANDSTONE	€p	CAMBRIAN SANDSTONES
⚒	QUARRY	Sh	SHALE	Ec	EAU CLAIRE
o	NEGATIVE LOCATION	Q	QUARTZITE	Dr	DRESBACH
O	OUTCROP OR ROCK DEPOSIT	T	TRAP ROCK	Fr	FRANCONIA
162	LOCATION NUMBER	Cgl	CONGLOMERATE	SL	ST. LAWRENCE & LODI
D	DELTA	Gr	GRANITES, PEGMATITE, ETC.	J	JORDAN
Dk	DELTA KAME	Dg	DISINTEGRATED GRANITE	Olm	LOWER MAGNESIAN DOLOMITE (PRAIRIE DU CHIEN FORMATIONS)
K	KAME			Osp	ST. PETER SANDSTONE
Ow	OUTWASH			Otg	GALENA-BLACK RIVER DOLOMITE (GALENA-DECORAH-PLATTEVILLE FMS.)
Pow	PITTED OUTWASH			Tr	TRENTON (DECORAH-PLATTEVILLE)
Tm	MORAINE, TERMINAL OR RECESSIONAL			Ga	GALENA
E	ESKER			Oc	RICHMOND (CINCINNATI) SHALE
L	LACUSTRINE DEPOSIT			Sn	NIAGARA DOLOMITE
C	CREVASSE FILLING				
Km	KETTLE MORAINE				
B	BAR, LAKE OR RIVER				
Bd	BEACH DEPOSIT				
R	RIVER GRAVELS, SAND & TERRACES				
S	SAND DUNE				
Kt	KAME TERRACE OR COMPLEX				
Al	ALLUVIAL DEPOSIT				
Du	DRUMLIN				

Examples:

X162 / Ow-80 — Means location 162 is a developed gravel pit and an outwash deposit with 80,000 cubic yards available. The yardage given is in thousands.

X10 / Bd-- — Means location 10 is an undeveloped beach deposit with unlimited yardage.

o5 — Negative locations when accompanied by a number indicate a previously recommended deposit now exhausted or undesirable.

oA — When the symbol is accompanied by a letter, such as "A" or "B" it indicates a negative note; the "A" or "B" as the case may be, refers to a report number which is shown in a legend at the bottom of the respective county map.

•A-1 — Drill hole indicated by a solid circle; the letter "A" refers to a report number indicated in a legend at the bottom of the county map; the number refers to the drill hole number in the report.

FIGURE 3

Figure 3. Symbols and abbreviations used on material survey maps.

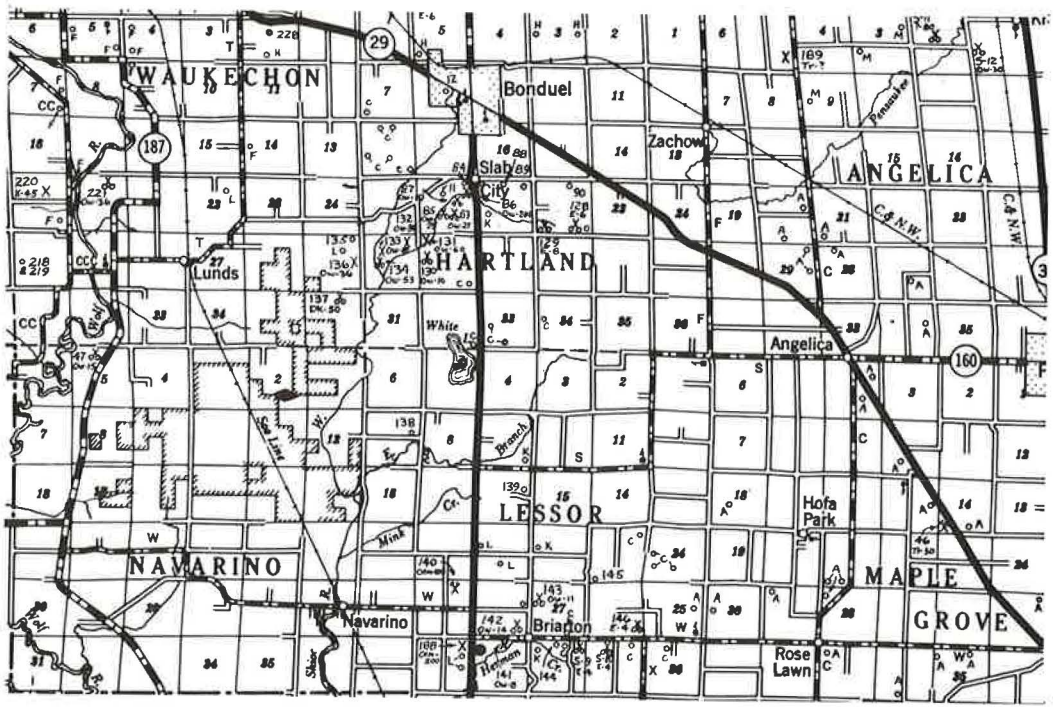

Figure 4. Portion of a typical material survey map.

acceptable aggregates exist, to expand on or verify the information provided by the State Geologist.

Such surveys are begun by gathering all geologic and pedologic data and plotting it on base maps or overlays. Aerial photographs are then examined and the probable boundaries of geologic provinces or areas are plotted. Sites which appear to be particularly promising as indicated by topographic form or geologic association are outlined on the base maps for field investigation.

The recently established Geophysical Unit of the Materials Section may later examine the suggested sites with seismic and resistivity instruments and report on the locations which appear to present the best possibilities. A power auger may later be used to prove out the character, depth and lateral extent of the selected locations.

USE OF SURVEY INFORMATION

As stated in the introduction to this paper, the basic purpose of surveys for potential sources of aggregates is to provide savings in the cost of transporting aggregates to the highway projects. The survey data, however, are also used as an aid in estimating the cost of projects, in providing information on the relative availability of aggregate deposits to contractors, and in suggesting to the road and bridge designer the general soil and rock conditions that may be expected in a specific project area.

The full value of the surveys is not always realized in each highway project, as for example, when no new acceptable aggregate deposits are found during a search on a specific project. The intentions of the search are valid, however, and the investment in the survey constitutes betting on the odds that a good local deposit might be found. If nothing else is achieved, the knowledge and experience gained by the personnel involved, the extension of soils and geological information, and the elimination of the project area from further investigation help to justify the expenditure of the survey. Also, the State Geologic and Natural History Survey derives invaluable information for its work from this cooperative activity.

ACKNOWLEDGMENTS

This paper was prepared with the assistance and guidance of J.R. Schultz, Engineer of Materials, and the advice of George F. Hanson, State Geologist.

Highway Materials Survey in Tennessee

DAVID L. ROYSTER, Chief Soils Engineer, Tennessee Department of Highways

This paper describes the aggregate survey conducted in 1948 and 1949 and published in 1950, and the present more detailed materials survey which was begun in 1959, discontinued, and then started again in 1962.

Due to a shortage of personnel, the present survey is being conducted on a part-time basis, and will probably require two years or more to complete. As the survey progresses, newer and better ideas and methods will no doubt be incorporated, but the basic plan as discussed in this paper will remain unchanged.

• IN 1950 the Division of Materials and Tests of the Tennessee Department of Highways published in book form county maps showing the location, type, and status of all known aggregate quarries and pits throughout the State. The 95 counties of the State are divided into four major divisions. The maps appear alphabetically by county according to division. Approximately two years was needed to check out thoroughly every quarry or pit site in the State for the original survey.

Each quarry or pit was examined, located on the county map (scale: 1 in. = 2 mi), and given a number. The status (active or inactive), type (limestone, marble, gravel, chert, and sand), and the owner or producer are also shown. The data on these maps are continually being brought up to date. As a quarry or pit is activated or deactivated, individuals possessing books are immediately notified of the changes. A complete revision of the original publication was issued in 1959.

PRESENT MATERIALS SURVEY

With the need for tremendous quantities of higher standard aggregate materials in the construction of the Interstate System, it has become necessary to make a more detailed inventory of Tennessee's aggregate sources. This survey, which is presently under way, consists of preparing detailed columnar or geological sections of all major active quarries, gravel pits, and sand pits throughout the State. Surveys of inactive quarries and pits near proposed Interstate alignments where haul distances from active aggregate sources are great are also being made at this time. As progress is made and as time permits, the present survey will be expanded to include potential pit and quarry sites in areas where construction materials are relatively scarce. These columnar and geological sections along with quarry or pit location maps will be published in loose-leaf book form at the completion of the survey.

This survey is being conducted by geologists of the Division of Materials and Tests with the aid of materials engineers and inspectors. Each quarry or pit is measured directly and logged in as much detail as is considered necessary. The amount of detail usually depends on the type of rock materials being quarried. Characteristic samples from individual strata are collected during the logging operation and are described in detail on the work copy of the log which is kept on file. The published log generally does not contain the detail of the work copy unless it is believed to be of engineering significance.

In quarries, columnar sections are used to show vertical lithologic changes and thicknesses where there is little or no deformation of the strata, that is, folding and faulting (Fig. 1). Geological sections are used where there is considerable folding and faulting or where there are significant horizontal lithologic changes (Fig. 2). In some cases, as in the Hoover quarry (Fig. 3), a combination columnar-geological section has

Paper sponsored by Committee on Surveying, Mapping and Classification of Soils.

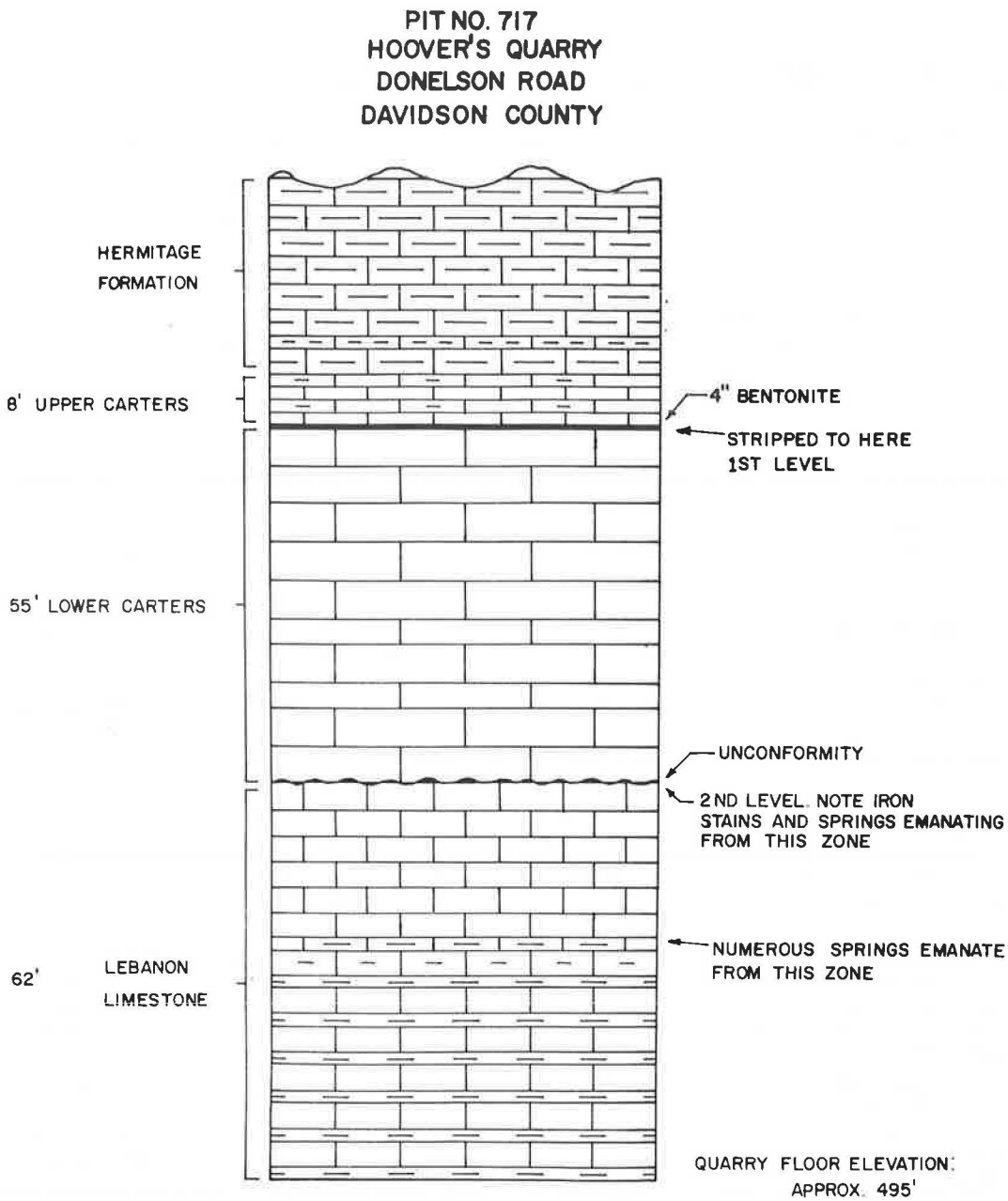

Figure 1. Columnar section showing two well-known and extensively quarried formations (Lower Carters and Lebanon) in Central Tennessee.

been used. When the structure of a quarry is not so complex as to warrant a geological section, and the dip of the strata is relatively uniform and in one direction, it is often necessary to make several logs along the direction of dip to show the complete sequence of strata being quarried (Fig. 4).

Measurements of individual strata in quarries with faces less than 100 ft, or where the strata are quarried in lifts up to 50 ft, are accomplished directly with a steel tape.

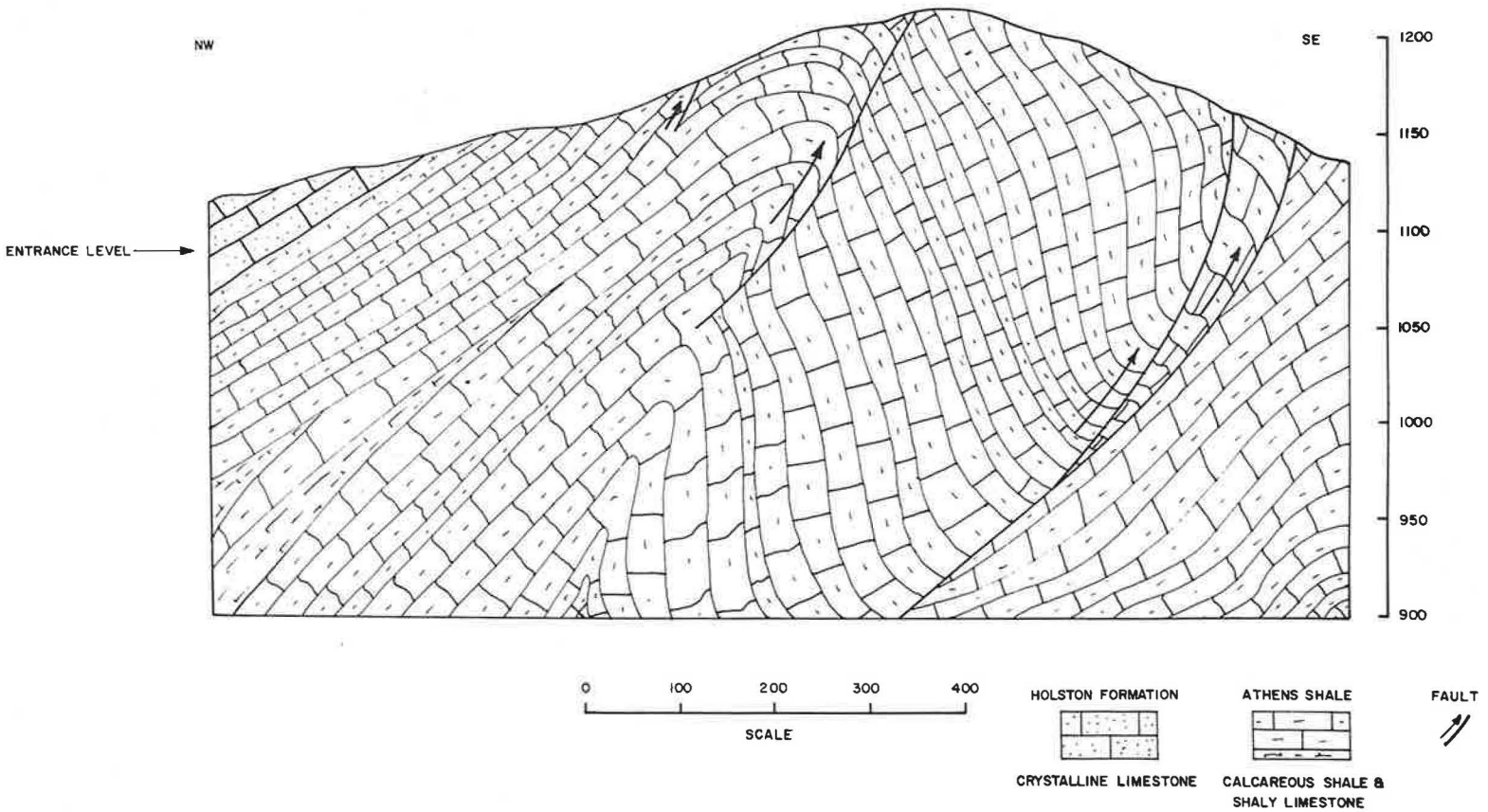

Figure 2. A generalized northwest-southeast geological section showing complexity of Webb quarry in McMinn County.

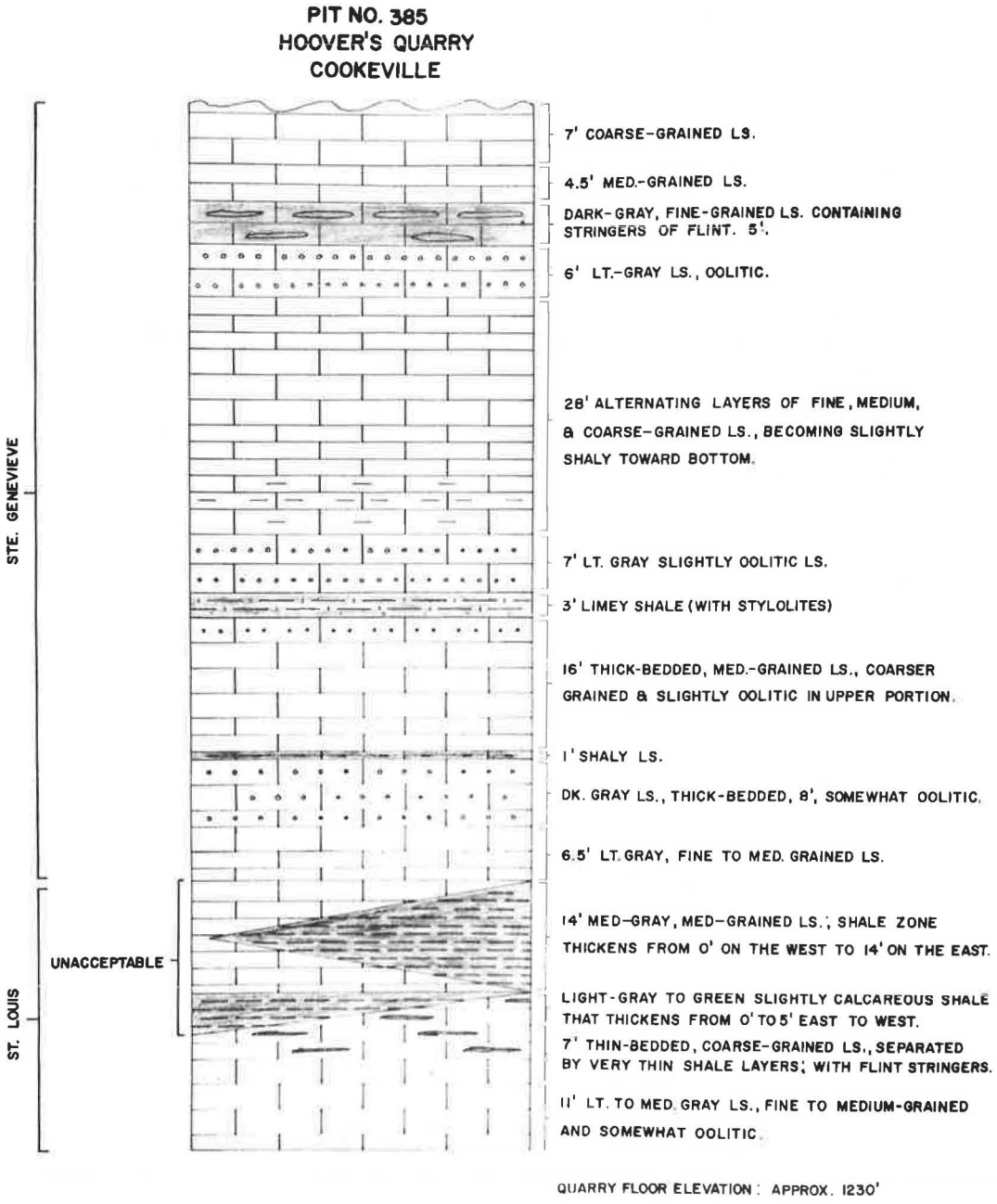

Figure 3. Combination columnar-geological section of quarry shown in Figure 1.

A rope or chain, graduated in 5-ft sections with red cloth strips that can be seen against the quarry face, is used for higher quarry faces. One end of the rope is weighted so that it does not lag or drape when hanging from a ledge or quarried level.

The most completely exposed section in the quarry is usually chosen as the section to be logged. However, due to the inaccessibility of some of the strata in the higher faces, the log may be drawn as a composite of strata studied in different, more accessible areas of the quarry.

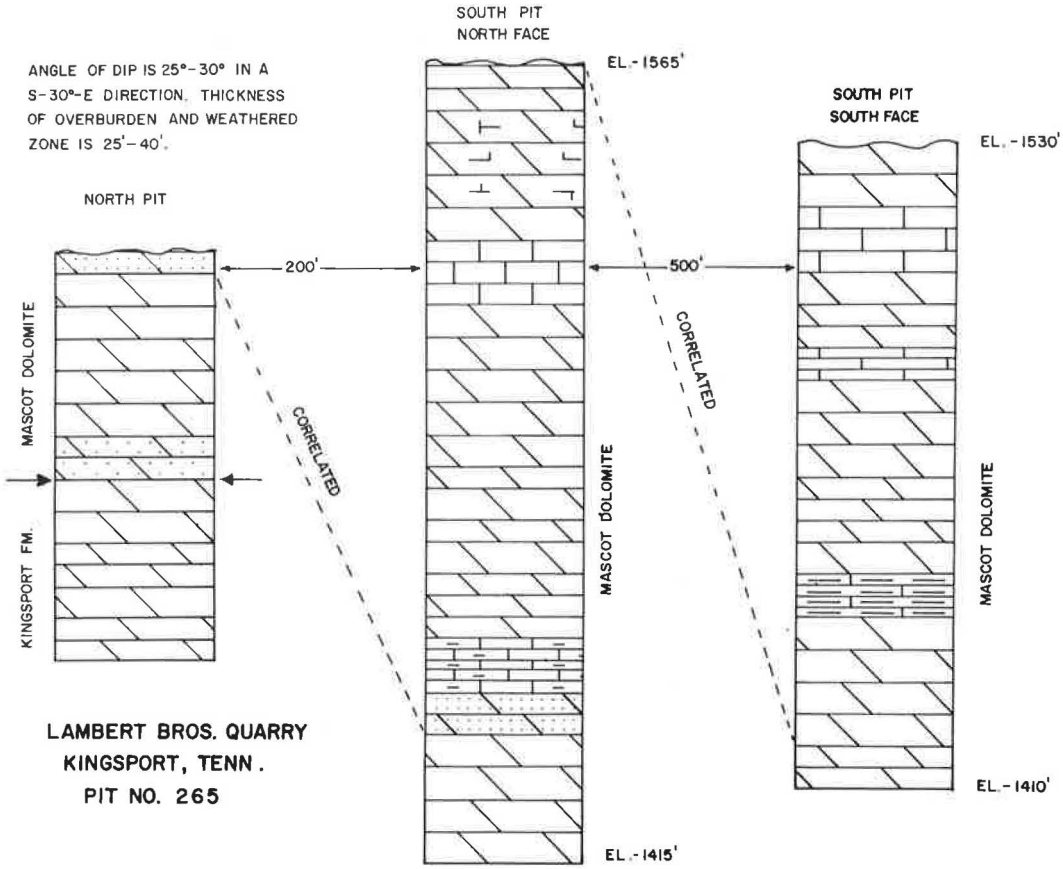

Figure 4. A series of columnar sections showing various strata encountered in a quarry where the dip is relatively uniform and in one direction.

Direct measuring and logging of quarries can be extremely dangerous; therefore, every possible precaution is taken to avoid accidents. When working along high ledges or along the edges of quarried levels the geologist usually ties a rope around his waist and secures the opposite end to a nearby tree, or has the inspector assisting him hold the loose end. Also, his Brunton compass, geological hammer, etc., are attached to his belt so that both hands are free for climbing. A hard hat is worn for protection against falling rock.

The scale of the log depends on the detail needed, as well as on the height of the quarry face. The scale is controlled also, of course, by the size of the paper used in the publication, which in this case will be $8\frac{1}{2} \times 11$ in. Quarries and pits with less than 100-ft faces are usually logged with a scale of 5 or 10 ft to 1 in. Quarries with faces greater than 100 ft, but again depending on the amount of detail required, may have a scale of 1 in. = 15 ft or 1 in. = 20 ft. Still smaller scales have been used in three or four instances where the geology is highly complex and the dimensions of the quarry are of unusual proportions. The Webb quarry (Fig. 2) is such an example.

In logging gravel deposits, the geologist usually describes and samples for testing the soil materials associated with the deposit; the reason being that these gravels normally do not contain sufficient fines (minus 40 sieve material), and it is often necessary to blend a suitable soil binder with the gravel to meet the specification. In West Tennessee, due mainly to the fact that there are no other materials available, gravel is the main base and aggregate source. A recent primary project in that part of the State called for a base material with the following specification:

Sieve Size	Total Percent Passing (Dry Wt.)
1¼ in.	100
1 in.	95-100
⅜ in.	50-80
4 M	36-65
16 M	20-40
100 M	8-15

The fraction passing the number 40 sieve (soil filler) shall have a liquid limit not greater than twenty-five (25), and a plasticity index not greater than six (6).

A gravel deposit like the one shown in Figure 5 was located nearby. However, because the gravel contained insufficient minus 40 sieve material, 10 percent binder derived from the loessial deposit overlying the gravel was added to form the specified mix.

In a more recent gravel-base project in Central Tennessee a sufficient quantity of gravel was located, but a binder that could meet the liquid limit requirements of the

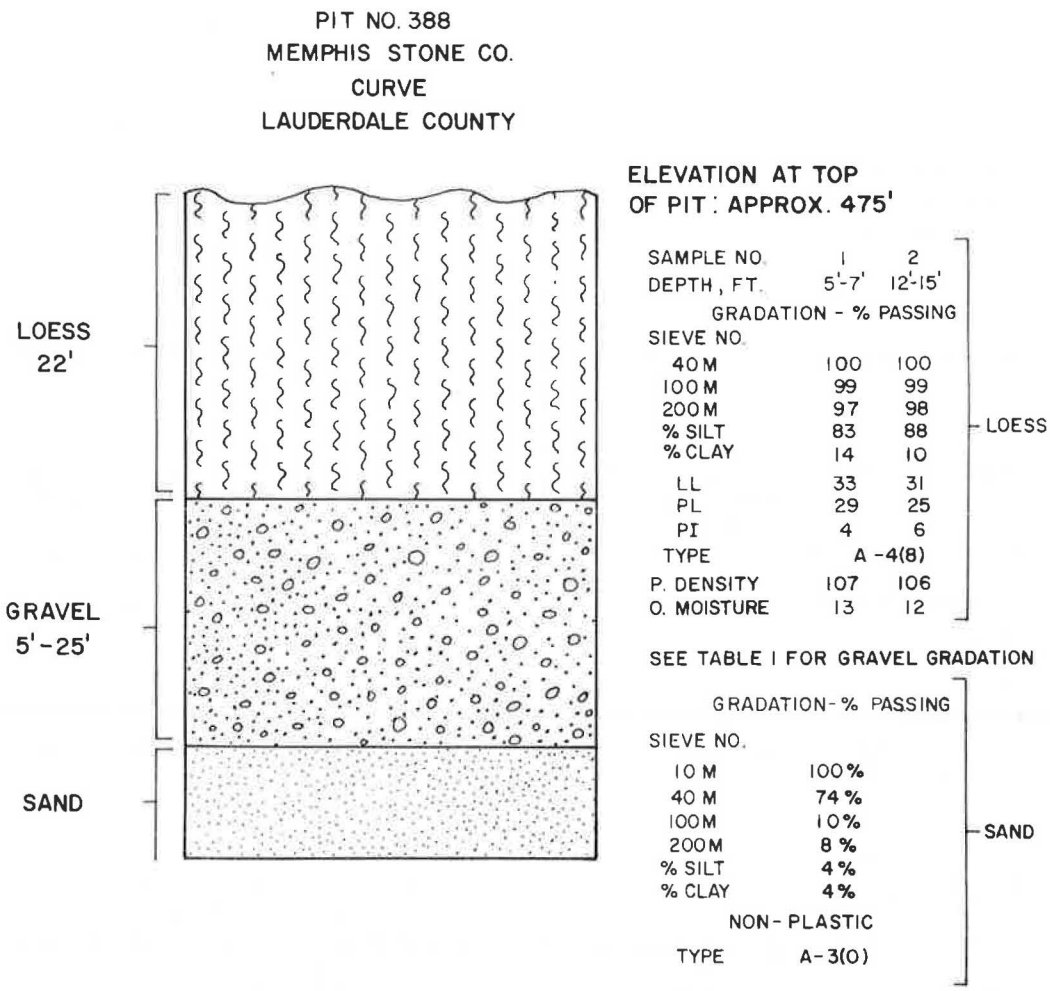

Figure 5. A typical gravel deposit in West Tennessee.

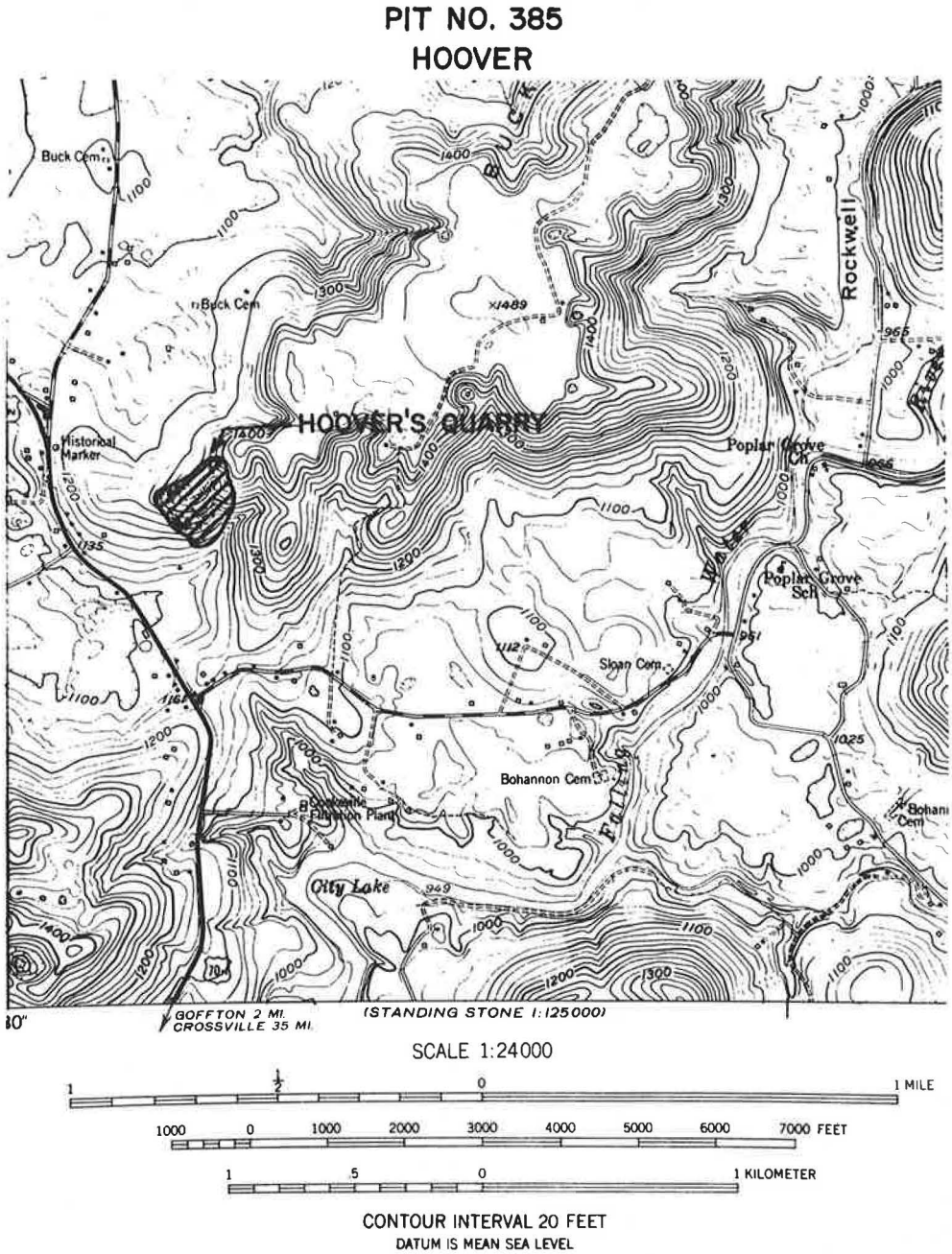

Figure 6. Typical example of a pit location map.

total mix specification could not be found in the project area. This, unfortunately, was not discovered until after construction had begun. The gravel base had been bid as an alternate by the contractor in lieu of crushed stone. This is an unusual case but it is an excellent example of the importance of considering every item, no matter how small, in making a materials survey.

The quarry and pit locations are spotted on 6-in. square cut-outs of U.S. Geological Survey, Corps of Engineers, or Tennessee Valley Authority topographic maps (Fig. 6).

Most maps are of the 7½-min quadrangle size (1 in. = 2,000 ft), with 15-min quadrangles (1 in. = 1 mi) being used where the larger scale maps are not available.

Elevations of quarry and pit floors, formation tops, etc., are determined with an aneroid barometer or taken directly from topographic maps. A Brunton compass is used to determine angles and directions of dip of the strata.

When a particular geologic formation is quarried extensively and the formation is relatively uniform over a wide area, then, to avoid repetition, only formation names, thicknesses, etc., are shown on the drawing (Fig. 1). These important aggregate-source-formations will be discussed in the text of the report in conjunction with the physiographic provinces in which they occur. In many cases, however, a description of the strata is given directly on the illustrated section (Fig. 3).

Once a quarry or pit has been logged, it is revisited periodically to determine if any new strata have been uncovered or if there have been any lateral changes in the strata already logged. If significant changes are noted, a new log is issued to replace the outdated log which can be easily removed from the loose-leaf binder.

Typical test data from each quarry or pit will be tabulated in the back of the publication (Table 1). These data, taken from the files of the Division of Materials and Tests, include results of tests conducted on quality samples over a period of three or four years. From these tables the user of the report should get some idea of the consistency of the materials furnished by the various quarries. Normally, test results from six or eight samples are given, depending on how long the quarry or pit has been operating or how many quality samples have been taken.

TABLE 1

COUNTY	PIT NO.	DATE	MAP PAGE NO.	SP. GRAVITY + 4	SP. GRAVITY − 4	DENSITY PCF (DRY)	OPTIMUM MOISTURE	LIQUID LIMIT	PLASTIC LIMIT	P.I.	SOUNDNESS	L.A. WEAR	GRADATION—% PASSING 2	1½	1	¾	½	⅜	4	10	20	40	60	100	200	% SILT	% CLAY
KNOX	411	11-2-60	27	2.75							98.8	19															
KNOX	411	5-8-61	27	2.70							99.4	19															
KNOX	411	5-10-62	27	2.74							99.2	19															
KNOX	316	3-23-60	29	2.78							99.1	19.5															
KNOX	316	4-19-61	29	2.79							99.4	16.8															
KNOX	316	4-24-62	29	2.79							99	19.9															
PUTNAM	385	5-2-62	67	2.68							95.5	22.4															
HAMILTON	260	8-2-60	59	2.75							80.8	23															
HAMILTON	260	3-28-61	59	2.71							97.4	24.6															
HAMILTON	260	3-6-62	59	2.74							98.1	24.4															
HAMILTON	260	6-13-62	59	2.72							94.2	23															
DAVIDSON	717	3-8-61	73	2.69							93.9	22.4															
DAVIDSON	717	10-16-61	73	2.68							97.3	23															
DAVIDSON	717	4-12-62	73	2.68							96.7	23.2															
DAVIDSON	717	7-23-62	73	2.69							97.2	26.8															
LAUDERDALE	388	9-12-62	89	2.46	2.60			25	16	9			98	93	87	81		68	54	47		12		5	5	2	3
MCMINN	267	9-7-60	63	2.70							95.9	15.8															
MCMINN	267	1-20-61	63	2.70							94.4	19.4															
MCMINN	267	1-17-62	63	2.71							91.0	18.0															
MCMINN	267	7-26-62	63	2.70							91.8	21.0															
OVERTON	150	10-13-60	65	2.64							94.5	28.8															
OVERTON	150	5-9-61	65	2.65							94.7	26.1															
OVERTON	150	7-17-62	65	2.68							96.2	25.0															

CONCLUSION

The present inventory has enabled geologists and engineers to become more familiar with the construction characteristics of the various formations quarried throughout the State. The problem formations and problem strata within formations, as well as the quarries in which they occur, having been pinpointed, can now be more easily checked and controlled.

This survey has also served to some extent as a teaching program for quarry inspectors, for in learning some of the basic principles of petrography and lithology from the geologist, and by studying the quarry foot by foot with the geologist, they have become better qualified as aggregate inspectors.

Research conducted on the skid-resistant qualities of various pavement aggregates has proved that aggregates derived from some geological formations are more skid resistant than others. This inventory should prove useful in the location of these more skid-resistant aggregate-producing formations and strata.

Both the original and the present surveys have enabled the Division of Materials and Tests to furnish the Plans Department, for their cost estimates, accurate and prompt information concerning haul distances from accepted quarry or pit sites to proposed construction sites.

The determination of construction material needs versus availability has been greatly facilitated by the issuance of the aggregate deposit location maps. The present survey should prove even more valuable as a source of such information.

Vermont Highway Materials Inventory

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This paper describes in detail the methods used by the Vermont Department of Highways in conducting an investigation and establishing an inventory of highway construction materials throughout the State. A short statement citing the need for such an inventory is followed by a discussion of the conditions peculiar to Vermont limiting the choice of methods used.

The present method of investigation was developed over a period of years after careful consideration of the limited factors involved. The small size of the State permits a more detailed investigation than would be economically feasible in a larger area. An intensive search for both rock and granular materials is conducted simultaneously in each town. The method used permits visual observation of the material at each of the test sites as well as sampling to determine acceptance or rejection for highway use. A copy of the form used to record data in the field is included in the paper.

Because the primary purpose of the survey is to furnish information to area engineers, district engineers, contractors, and other interested personnel, most of whom have only a limited knowledge of geology, the method of presenting the reports is devised with this is mind.

A description is given of the final report in which the results of the survey are tabulated. The report is compiled in pamphlet form for each town, and includes surface geology maps of both rock structure and granular materials. The report is written with its intended use in mind. Hence, the maps contain little geologic information such as rock formations, glacial features, etc., but are presented in terms of generalized rock types and granular materials. The locations of the various tests are plotted on the maps and referred to data sheets which describe the material and the sampling results in each test. Facsimiles of the various maps and data sheets are included in the paper.

Finally, the effects of the investigation on the highway program are enumerated. By recognizing new sources of material, it has reduced the cost of highway construction, and affected the design of proposed highways. Many new sources, which were not found suitable for State or Federal use, are being used by the towns.

Paper sponsored by Committee on Surveying, Mapping and Classification of Soils.

•THE Material Survey Project was formed in 1957 by the Vermont State Department of Highways in cooperation with the U.S. Department of Commerce, Bureau of Public Roads. Its prime object is to compile an inventory of highway construction materials in Vermont. Prior to the efforts of the personnel of this survey, searches for highway construction material were conducted only as the immediate situation required. Thus, only limited areas were surveyed and no over-all picture of material resources was available. However, through this project, prior knowledge of locations of suitable material is made available to the engineers, contractors and other interested personnel.

Numerous factors limit the choice of methods to be used in conducting the survey. Foremost of these is the fact that, up to the time of the initiation of the project, no other survey equal to the desired scope was as yet in progress. Hence, no precedent had been established for such a project. Furthermore, there had been, as yet, no aerial photography of the State other than limited strip photography of small areas. Consequently, it was necessary to devise suitable base maps.

The physical characteristics of the area have much influence on the method to be used in carrying out the project. The climate restricts the field season to only seven months, thus concentrating the field work into the warmer months while as much office work as possible is retained for completion during the winter. The small size of the State, 9,276 miles of land area, makes possible a more detailed study than would be feasible in a larger area. Probably topography is the greatest single factor affecting the procedure to be used in conducting the survey and in recording the results. The terrain of the area is rugged, ranging in elevation from approximately 95 to 4,400 ft above sea level. The higher elevations forming the Green Mountains stretch in a continuous line north and south through the center of the State, thus forming an effective barrier to east-west communication. There are only three main east-west highways in the entire length of the State, a distance of approximately 160 miles. The rugged character of the terrain indicates a wide variety of topographical conditions and of varying types of materials within short distances, thus indicating that the survey must be conducted on the basis of the smallest possible political divisions. The rugged terrain also indicates the presence of numerous stream valleys, potential sources of granular deposits of fluvial and glaciofluvial origin. With the exception of the areas of extreme elevation and cultivated areas in and near the valley floors, the entire region is covered by dense timber, thus preventing the effective widespread use of aerial photography. Its use must be limited to serve as a preliminary procedure in open areas. However, with the completion of the aerial survey of the entire State this year and training of the project personnel in aerial photo interpretation, it is hoped that the used of aerial photography may prove to be a more valuable tool than it is at the present time.

The geologic conditions present in the area limit the use of certain methods of exploration, particularly in regard to the search for rock suitable for highway use. This is a region of intense diastrophism, indicating rock types resulting from various stages of metamorphism and with greatly disturbed structure. Contrary to general belief, the "backbone of the Green Mountains" is not granite, an igneous rock, but a rather poor quality, undependable schist or phyllite. The resistivity method has been attempted by the department in other fields of exploration but with rather questionable results. This project attempted to use the resistivity method to determine the extent of granular deposits but with little success. The intense changes of material within short distances render this method undependable at the present time. Perhaps with the training of personnel and the use of improved instruments this method might possibly show more favorable results.

The successive periods of glacial activity imposed on the region with intervening periods of erosion resulted in conditions which have considerable influence on the procedure to be used in the survey. The intense glaciation resulted in the deposition of materials into features of glacial and glaciofluvial origin which are generally discernible.

With all the foregoing factors under consideration, a procedure to be used in the conduct of the survey has been developed which intends to give the most useful information through the most efficient application of manpower and equipment. It must

be kept in mind that, in actuality, two surveys are being conducted simultaneously; viz., a survey of granular deposits containing sand and gravel and a survey of sources of acceptable rock. The survey is carried out by a crew consisting of four graduate geologists employed on a permanent full-time basis, and two part-time temporary employees, usually students majoring in geology, hired during the field season. A ½-ton pickup truck is furnished by the department as are numerous small tools. When available, a backhoe and operator are furnished by the district highway office within whose jurisdiction the survey is being conducted. When this equipment is not available through the district office, it is rented under contract from private enterprise within the area under consideration at an average cost of $7 per hour for equipment and operator.

The total cost of the project since its inception in 1958 through 1962 inclusive is $119,203. There were 36 towns, representing 1,252.32 sq mi of the State's 246 towns, surveyed at a cost of $95.19 per square mile. This basis of cost evaluation should be accepted with reservation. It must be kept in mind that this survey is being conducted for the purposes of locating acceptable sources of granular and rock materials. This procedure results in two surveys being conducted simultaneously in a town. The aforementioned cost per sq mi includes both surveys. In view of the Interstate construction program under way, it was advisable to initiate this inventory in those towns traversed by the proposed Interstate routes. These routes generally follow the major valleys along which the granular deposits are concentrated. This concentration of granular deposits necessitates considerably more investigation and sampling. It is reasonable to assume that the cost per square mile will be lowered, as the survey proceeds to the higher elevations, where granular deposits are lacking.

Following is a summary of cost for the calendar year 1961, the last year for which detailed figures are available.

SUMMARY OF COST FOR CALENDAR YEAR 1961

Total days worked in field	526
Total days worked in office	540
	1,066 man days
Salaries	$21,609.04
Miles traveled by car - 28,936 @ $0.08	2,314.88
Subsistence	4,225.65
Backhoe	1,895.38
Material, includes $800 for maps	1,032.70
Total	$31,077.65

The State is divided into 246 towns, which range in size from 3.4 to 72.4 sq mi. Consequently, the survey is conducted by towns, this having been chosen as the political unit most expedient for the purpose.

The method employed by the project in the survey of possible sources of sand and gravel for highway construction is divided into two main stages, office investigation and field investigation. The office investigation is conducted primarily during the winter months and comprises the mapping of possible potentially productive areas as indicated from various references. D. P. Steward of Miami University, Oxford, Ohio, is presently engaged in a study of the glacial geology of the State. This study was initiated in 1956 and is sponsored jointly by the Vermont Geological Survey and the Vermont Department of Highways. The survey of glacial deposits mapped by Stewart proves to be valuable, particularly when used in conjunction with other references such as soil type maps, State geologist's reports, to a limited extent aerial photographs and United States Geological Survey topographic maps. The last two are used in recognizing and locating features indicating glacial deposits and in studying drainage patterns. In addition, the location of existing pits, when known, is shown

AREA NO: 1

VERMONT

MATERIALS SURVEY

TOWN: HARTLAND MAP IDENTIFICATION NO: 1 DATE: 8-18-61

OWNER & LOCATION: W.R. SCOTFIELD - PIT LOCATED 250 FT. S.W. OF INTERSECTION OF U.S. ROUTE 4 AND VT. ROUTE 12.

LABORATORY NO:----------	90473			
RESULTS:----------	OK-201A & 102A			
FIELD TEST NO:----------	1			
GRANULAR MATERIALS	GRAVEL			
METHOD OF SAMPLING:----	HAND SHOVEL			
AMT. OF OVERBURDEN:----	0-1			
DEPTH OF SAMPLING:-----	1-6			
TYPE OF MATERIAL:------	GRAVEL			
TYPE OF BOTTOM:--------	GRAVEL			
COARSE MATERIALS				
METHOD OF SAMPLING:----				
ROCK FORMATION:--------				
TYPE OF ROCK:----------				
DIST. BETW. SAMPLES:---				

REMARKS: AVERAGE 8.0 TO 10.0 FT. FACE AROUND PIT. MATERIAL DEPLETED ON EASTERN AND NORTHERN SIDES. PIT NEARLY DEPLETED WITH LIMITED EXPANSION POSSIBILITIES TO THE SOUTHWEST. TEST HOLE IN FLOOR OF PIT CENTER SHOWS SILT BOTTOM.

SKETCH

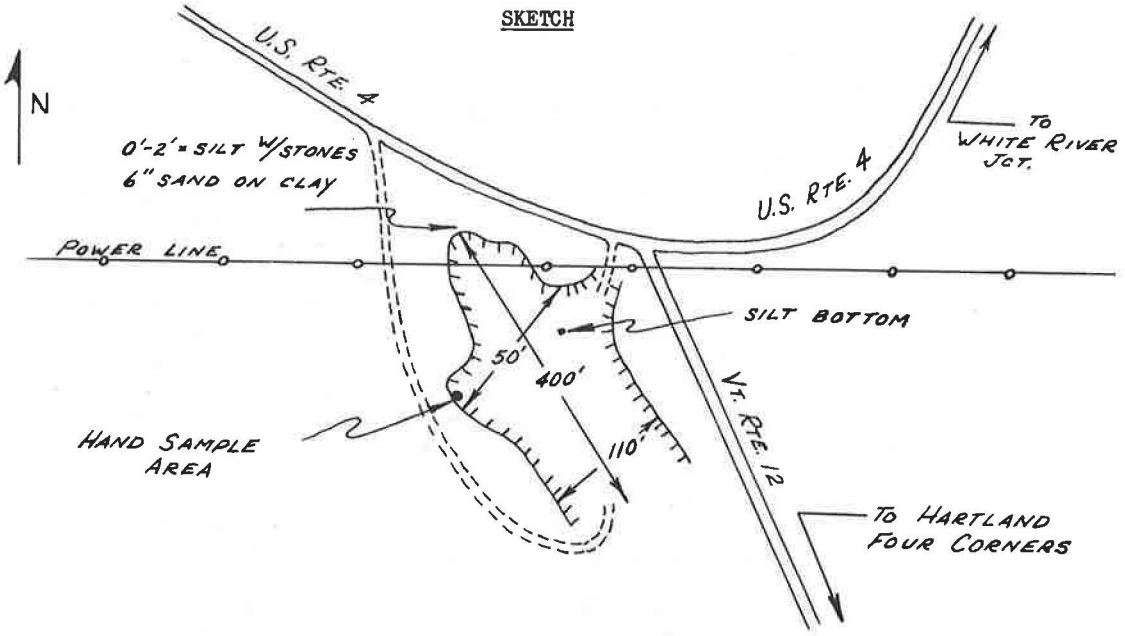


Figure 1.

on the topographic quadrangle map. The locations in which samples were taken by other individuals are noted and shown on the same map, when possible. This information is obtained from an active card file compiled by the Highway Testing Laboratory. It was readily apparent that the latter information was gathered over a period of years by many persons and consequently lacks the organized approach and detail required for effective use.

The second stage of the investigation is begun in the field by making a cursory preliminary survey over the entire area noting physiographic features giving evidence of glacial or fluvial deposits. These locations are later examined by digging test pits with a backhoe to a depth of approximately 12 ft. The material is carefully examined "in situ" and a description is noted on a specially devised field sheet together with a rough sketch of the area (Fig. 1). The material is then sampled and the samples are submitted to the Highway Testing Laboratory where they are tested for gradation and stone wear, the latter by the Deval Method (AASHO T-4-35). The number of test holes made in each town varies from as few as 50 to as many as 200 or more depending on the conditions encountered.

The routine employed by the project in the survey of possible sources of rock for highway construction is, in general, very similar to that used in the granular survey. It, also, is divided into two main stages, the office investigation and the field investigation. The first is conducted primarily during the winter months and comprises the mapping of rock types as indicated in various reference sources. Among the many references utilized, the most valuable at the present time has proved to be the "Centennial Geologic Map of Vermont" published in 1961 by Charles G. Doll, State Geologist. The other references differ considerably in dependability due to new developments and studies contributing to the obsolescence of a number of reports. In addition, the results of samples taken by other individuals are analyzed and the locations in which these samples were taken are mapped when possible. In other words, as complete a correlation as possible is made of all the information available concerning the geology of the area under consideration.

The second stage of the investigation is begun in the field by making a cursory preliminary survey over the entire area. The information obtained in this survey, together with the information assimilated in the first stage of the investigation is employed to determine the areas in which the testing and sampling will be concentrated. When a promising source is encountered as determined not only by rock type but also by volume and the existence of a good working face, chip samples are taken with a hammer and submitted to the Highway Testing Laboratory for testing by the Deval Method (AASHO, T-3). Recently, equipment has been acquired by the Laboratory which permits testing by the Los Angeles Method (AASHO, T-96). Consequently, future samples may be tested by this alternate method. It is kept in mind that the samples taken by the chip method are often in the weathered zone of the outcrop and consequently may show a less satisfactory test result than the fresh material deeper in the body of the rock structure. Should the results of this test prove satisfactory, further samples are taken by drilling to a depth of 3 ft and blasting at intervals across the strike or trend of the outcrop. Occasionally, due to the uniformity of the material and satisfactory test result from the chip sample, it will not be deemed necessary to drill and blast, in which case the material is included as a satisfactory source on the basis of the results of the chip sample. Again, as in the case of the granular survey, the material is carefully examined and the observations noted in detail on the field sheets together with a rough sketch of the area (Fig. 2).

In every instance, in regard to both the rock and granular samples, the material is evaluated by the laboratory as to possible use. Experience has shown that it is essential to sample the material in each feature, particularly in each rock type, regardless of its appearance, in order that an official record may be obtained.

The chief of party in the field determines the exact point at which a test will be made. In rare instances, the property owner will restrict testing to certain areas due to the presence of valuable crops. However, the landowner usually considers the program a service furnished by the State which will increase his knowledge of the material contained on his property.

AREA NO: 2

V E R M O N T

M A T E R I A L S S U R V E Y

TOWN: HARTLAND MAP IDENTIFICATION NO: 5 DATE: 8-9 61

OWNER & LOCATION: VELNA HAWKINS PROPERTY, LEASED TO PERINI CONST. CO. FOR QUARRY OPERATIONS --0.6 MI. SSE OF N. HARTLAND P.O.

LABORATORY NO:----------	89909		
RESULTS:----------	2.8%		
FIELD TEST NO:----------	1		
GRANULAR MATERIALS			
METHOD OF SAMPLING:----			
AMT. OF OVERBURDEN:----			
DEPTH OF SAMPLING:-----			
TYPE OF MATERIALS:-----			
TYPE OF BOTTOM:--------			
COARSE MATERIALS	ROCK		
METHOD OF SAMPLING:----	CHIP		
ROCK FORMATION:--------	ORFORDVILLE		
TYPE OF ROCK:----------	QZTE.		
DIST. BETW. SAMPLES:---	50' ACROSS STRIKE		

RESULTS: QUARTZITE (IN CHLORITE ZONE) LYON'S ORFORDVILLE FORMATION (CHLORITE SCHIST) STRIKE = N5°E DIP = EAST 64° QUARRY HAS 40' FACE, WIDTH 120', TEST #1 TAKEN ALONG EASTERN FACE OF QUARRY - MATERIAL USED BY PERINI CORP. IN THE CONSTRUCTION OF HARTLAND. DAM.

SKETCH

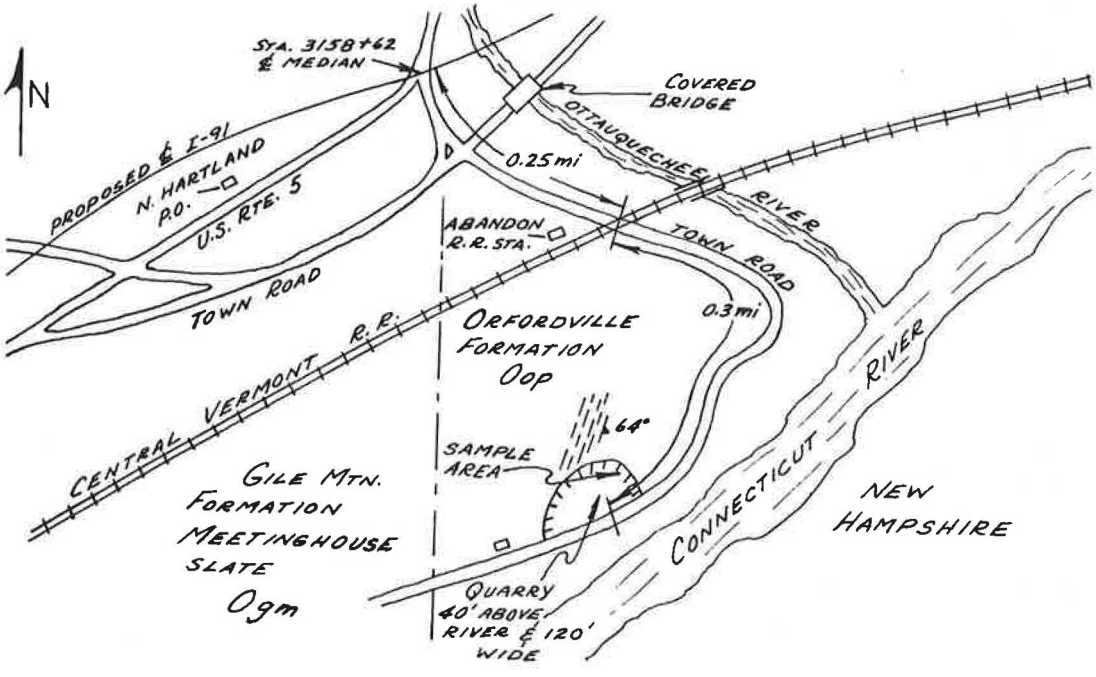


Figure 2.

In a detailed study such as this, the second stage or field survey consumes up to six weeks time per town, depending on the location and type of material encountered.

After the survey of each town is completed, the results are compiled in a town report in pamphlet form. Included in the town report are two maps: one indicating locations of granular tests as well as types of granular deposits, the other denoting the locations of rock tests as well as rock types. As noted previously, at the time the survey was initiated there were no aerial photographs available, nor was there any other map suitable for use as a base map on which to denote the test locations. Consequently, the United States Geological Survey 15-min topographic quadrangle maps (scale 1:62,500) are employed for this purpose. Each town is reproduced from the quadrangle separately and enlarged to the scale of 1 in. = ½ mi. The base maps are on Cronaflex film, thus simplifying the reproduction process. Two maps per town for 20 towns are obtained each year by contract from private firms at a cost of from $800-$1,000. On receipt of the Cronaflex base maps, the project inscribes the information obtained in the field on the maps. The maps may then be reproduced by either the contact print or Xerox method (Figs. 3 and 4). With the assistance of the personnel of the United States Geological Survey a simple legend for the rock map was determined. The material source areas are then colored by hand. It is felt that hand-coloring is very time-consuming and is the main deterrent to any volume production of the reports. However, no other satisfactory method of color reproduction has been developed as yet.

The town report also contains Data Sheets for both the rock and granular surveys (Figs. 5 and 6). The Data Sheets contain detailed descriptions of each test together with the laboratory results, identified to locations on the maps by symbols and identification numbers. This information is obtained from the field sheets which, together with the laboratory reports, are kept on file in the project office. Several tests are usually conducted in each area represented on the map by an identification number, the number of such tests being more or less arbitrarily determined either by the character of the material tested or by topography.

Also contained in the town report is a technical summary of the rock formations encountered in the town. Although the report is written in a non-technical style, keeping in mind its intended use by the contractor or construction man who is unfamiliar with geologic terminology, it is felt that a technical description of rock formations which is set apart from the main body of the report would prove valuable to those with training in geology.

The results of the survey are distributed as widely as possible both within the department and to other interested parties. Within the department, information is submitted to the Planning Division for use in establishing cost estimates for specific projects. In one case, plans for a project specified that the road would be constructed with subbase of crushed rock. However, in its routine survey of the area the Materials Survey located sufficient acceptable gravel in close proximity to the proposed project to permit revision of the plans at a saving of many thousands of dollars. The Construction Division frequently requests information concerning potential sources of material. The Right-of-Way Department employs the information in determination of property values of land to be acquired for projects. Copies of the reports are submitted to local highway districts to facilitate the development of new sources of material.

Town officials often request copies of the town reports to aid in the search for new sources of material. In the few instances where the personnel of the project has had the opportunity to return to a town which had been surveyed in previous years it was observed that many of the sources located by the survey were being exploited by the town.

Contractors obtain copies of the reports to enable them to make intelligent bids on projects. Often the presence of numerous potential sources of material increases competition, thus lowering the cost of construction.

It should be kept in mind that the survey is not conclusive, but the towns which have been completed should be resurveyed at stated intervals in order to determine the amount of material remaining and thus keep the reports current.

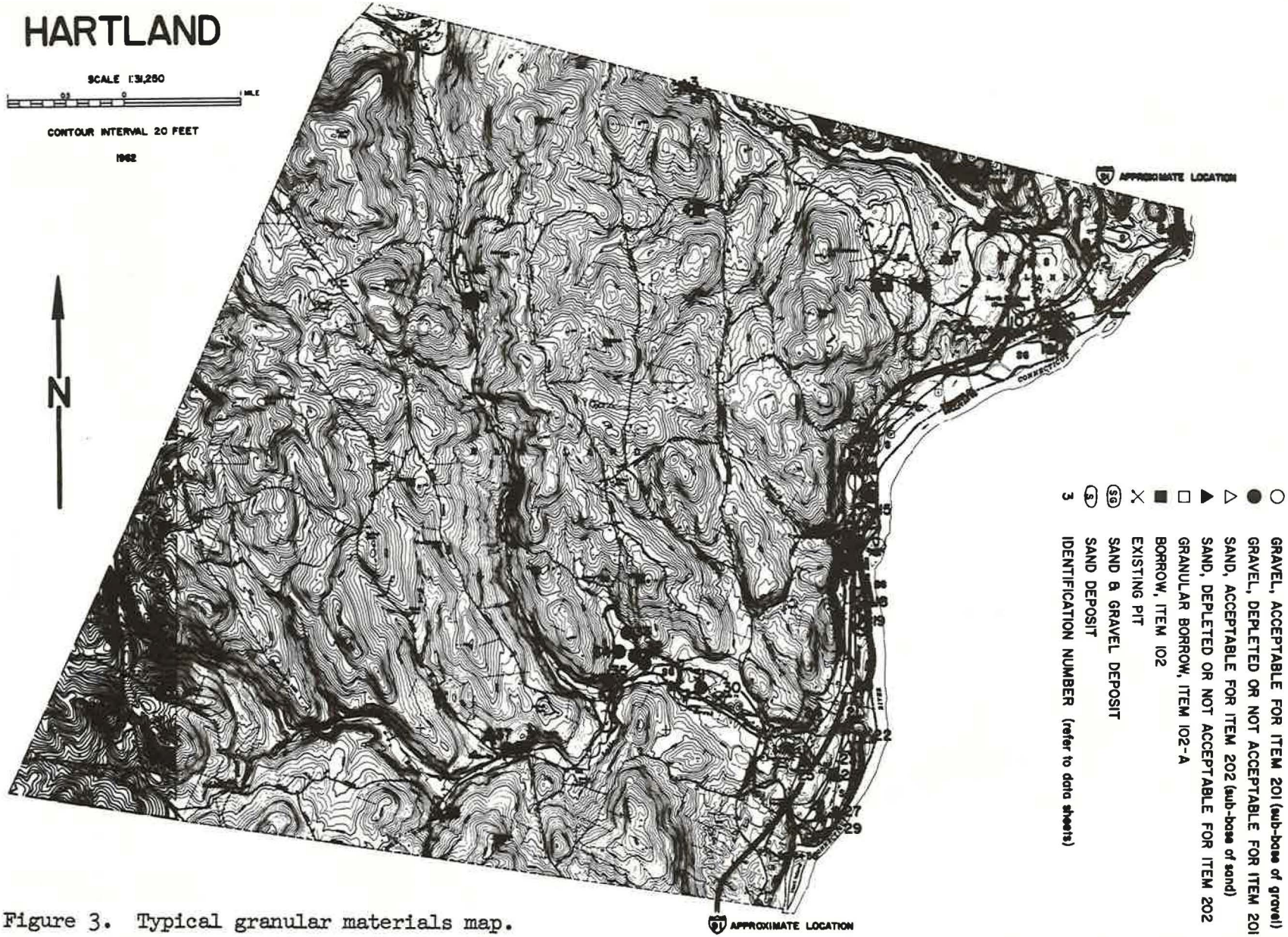


Figure 3. Typical granular materials map.

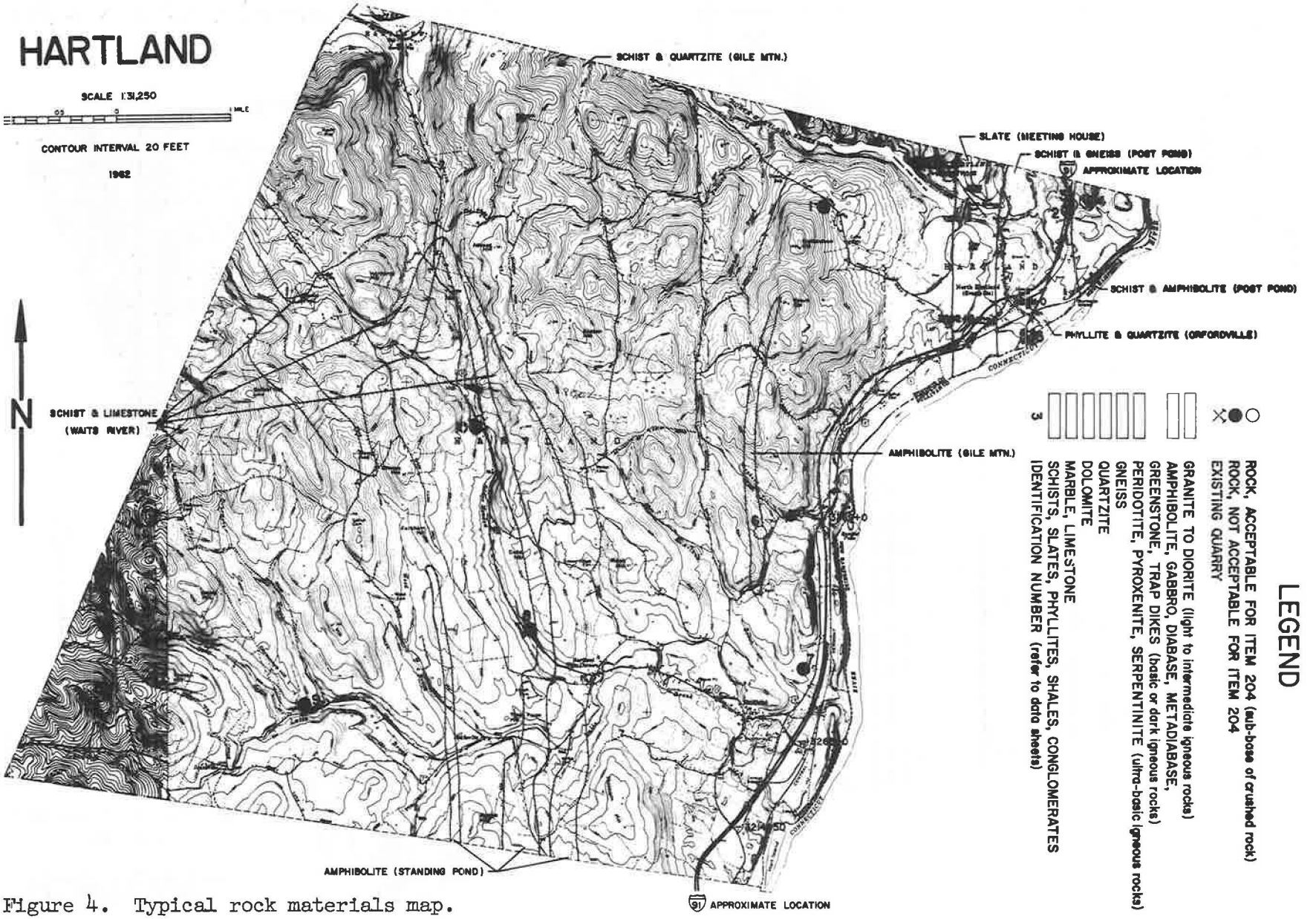


Figure 4. Typical rock materials map.

HARTLAND ROCK DATA SHEET NO. 2

Ident. No.	Field Test No.	Year Field Tested	Rock Type	Existing Quarry	Method of Sampling	Abrasion AASHO T-3	Distance Between Samples (ft)	Remarks
5	1	1961	Quartzite	Yes	Chip	2.8%	50' across strike	Owner: Velna Hawkins. Property leased to Perini Bros. Construction Co. for quarry operations. Quarry has a 40' face and is about 120' in width. Rock is quartzite, strikes N5°E and dips easterly 64°. Test #1 taken along eastern face of quarry, across strike. Acceptable for Item 204, sub-base of crushed rock.
6	1	1961	Amphibolite	No	Chip	4.4%	80' across strike	Owner: Turner P. Maxham. Field outcrops southwest of barn. Strike is north-south (about 260') and area is about 80' wide. Rock is massive & dark; looks like a gabbro. Limited by schist to the southwest. Acceptable for Item 204, sub-base of crushed rock.
7	1	1961	Phyllite	No	Chip	11.9%	15' across strike	Owner: Mrs. Archie Goodsell. An outcrop of phyllite and phyllitic quartzite. 400' west of US Rt. 5. Breaks platy, strikes north, dips 45° eastward. Rejected for Item 204, sub-base of crushed rock.
8	1	1961	Phyllite	No	Chip	14.4%	15' across strike	Owner: Kenneth Hunt. A roadside outcrop on eastside of Vt. Rt. 12 Rock is phyllite, gray in color. About 120' across outcrop, and 30' in height. Rejected for Item 204. Has 14.4% abrasion.

Figure 5.

HARTLAND GRANULAR DATA SHEET NO. 1

Ident. No.	Field Test No.	Year Field Tested	Depth of Sample (ft)	Over-Burden (ft)	Exist-ing Pit	Volume Estimate (cu yds)	Sieve Analysis % Passing 1½"	#4	#100	#270	Color AASHO T-21	Abrasion AASHO T-4-35	Passes VHD Spec.	Remarks
1	1	1961	1-6	0-1	Yes		-	56.3	9.0	3.0	3½	23.0%	Gravel	Owner: W. R. Scotfield. Pit at top of hill south west of junction of US Rt. 4 and Vt. Rt. 12. Material depleted on eastern and northern sides and pit bottom. Limited possibility on southwest. Acceptable for Item 201A, sub-base of gravel.
2	1	1961	1-9	0-1	No		-	38.2	3.0	1.0	1	29.8%	Gran. Borrow (Grav)	Owner: Eldridge Cowdry. Pit at southern end of a long esker. Test #1 taken south of pit. 0-1 ft. sand, 1-9 ft. fine gravel, fine sand bottom. Rejected for Item 201A, sub-base of gravel. Has per cent of wear 29.8% maximum allowed is 25.0%.
	2	1961	0-7	0	Yes		100	100	49.0	11.25	1	--	--	Test #2 taken in floor of pit. Wet sand at 7' Rejected for Item 202 sub-base of sand and Item 102A, granular borrow. Has 11.25% passing No. 270 mesh. Maximum for Item 102A is 10%. Has 49.0% passing No. 100 mesh. Maximum for Item 202 is 15.0%. Has 11.25% passing No. 270 Max. allowed is 5.0%.

Figure 6.

Methodology of the Oklahoma Materials Inventory Research Project

MITCHELL D. SMITH, Geologist and Project Engineer, Oklahoma Department of Highways

The known supply of quality aggregates in Oklahoma is very limited and is rapidly becoming exhausted in many localities. This paper describes the methodology used to locate new sources of materials and to determine the quantity of materials available from previously known sources and from potential sources located during the inventory project. Basic steps of the inventory studies include (a) library study (the assembling of existing records of previously located material sources); (b) process of existing data (the listing and publishing of previously located potential material sources); (c) field data and sampling (including familiarization courses, preliminary field investigations and establishing of procedures and schedules); (d) laboratory testing and analysis of materials; and (e) consolidation of data and final report. Approximately one-third of the State has been surveyed since the project was initiated in 1958, and preliminary results indicate that the research project has already increased considerably Oklahoma's known sources of quality aggregates for highway construction.

• OKLAHOMA, like other States, is concerned with the increasing problem of the supply of quality aggregates. In Oklahoma there are some localities where the supply is abundant, while there are others where the known sources of supply are limited and becoming exhausted. This situation often requires shipping of quality aggregates long distances and gives rise to the cost of aggregates. The cost of aggregates is high and will continue to increase as the present supply diminishes. As a result of this increasing problem, the Oklahoma Department of Highways initiated a research project, titled "Oklahoma Materials Inventory Research Project," in the early part of 1958 in an effort to determine the availability of materials from known sources and to develop new sources of highway construction materials. The project is being operated in cooperation with the U.S. Bureau of Public Roads.

Construction materials are being located throughout the State, their quantities estimated, and the materials classified for possible use in highway construction. Material sources located and estimated quantities are being catalogued. This information is made available for use in future highway construction projects.

The research procedure includes five major phases, as follows:

1. Library study.
2. Processing of existing data.
3. Field data and sampling.
4. Laboratory testing and analysis of materials for possible use.
5. Consolidation of data and final report.

The project began in June 1958 and the following had been accomplished to December 1962.

Paper sponsored by Committee on Surveying, Mapping and Classification of Soils.

LIBRARY STUDY

Library study consisted of assembling existing records of previously located material sources within the highway department's materials laboratory and in a publication prepared by the Oklahoma Emergency Relief Administration in 1934. These existing records covered a period of 25 years and are as follows:

1. Active and inactive project files of the soils section covering the period 1949 to 1959, inclusive.
2. Ledger files maintained by the physical section covering the period 1936 to 1959, inclusive.
3. A book prepared by the Oklahoma Emergency Relief Administration in 1934, titled "Construction Materials of Oklahoma." This is the same as the Oklahoma State Mineral Survey of 1934-1936.

PROCESSING OF EXISTING DATA

All locations of material were listed by county, legal description, and when available, laboratory file number, project number, and the date they were sampled and tested.

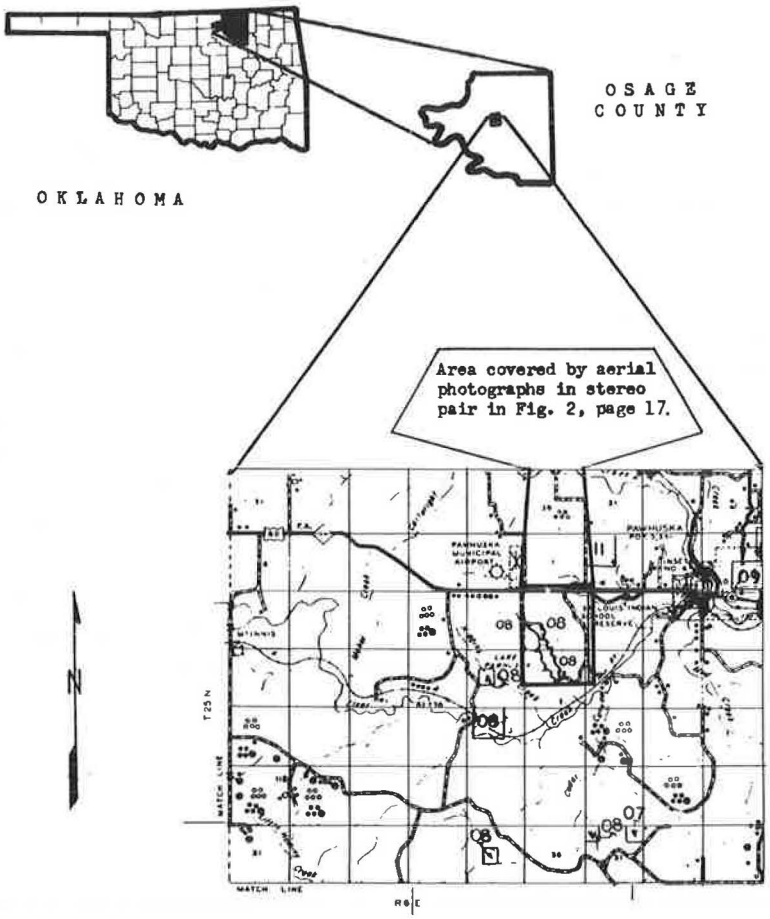


Figure 1. Portion of materials inventory map of Osage County, Oklahoma.

This listing was published and titled "Oklahoma Materials Inventory Research Project Potential Material Sites," and dated February 1960. The publication was made available to personnel of the department and sold for the cost of publishing to individuals outside the department.

Material locations plotted by type of material on sectionalized county maps were prepared and published. These maps were titled "Oklahoma Materials Inventory Research Project Potential Material Sites," and dated February 1960. The material locations were plotted on the maps by the use of a numerical code number for each particular type of material within the quarter of the section in which the material was located. An appropriate legend or explanation appears on each county map explaining the code number and type of material (Fig. 1)

One set of similar maps, but using color symbols instead of the numerical code, was prepared for use within the department only.

The numerical code number and color symbol established for each type of construction material are as follows:

Numerical Code Number	Type of Material	Color Symbol
01	Anhydrite	Purple X
02	Caliche	Olive drab green X
03	Chert	Blue with black lines
04	Conglomerate	Yellow with red dots
05	Dolomite	Light green (bice green)
06	Granite	Blue with pink lines
07	Gravel	Blue
08	Limestone	Crimson red circle
09	Sand	Yellow
10	Sandstone	Brown
11	Suitable soil	Yellow with black X
12	Suitable soil and sandstone	Yellow with black X and brown +
13	Gravel and sand	Yellow with blue lines
14	Caliche and sand	Yellow with olive green drab X
15	Asphalt sand (natural)	Circled A in black color
16	Rip rap	Black circle with RR in center with appropriate color symbol

The materials were grouped according to their usability, and plotted by type of material on three different sectionalized State maps: one map for fine and coarse aggregate, one for soil suitable for stabilization, and another for rock suitable for rip rap material.

Transparent overlays were made for the fine and coarse aggregate and soil suitable for stabilization maps. These overlays facilitated a correlation of the plotted locations of material with a geology map and a soil association map. The overlays are of the same scale as the Geologic Map of Oklahoma and the Oklahoma Soil Association Map.

The existing material records were used to determine the availability of material from known sources, to indicate areas where there is a scarcity of material, and to serve as a guide for locating new sources of material.

The following tabulation indicates the type of material and the number of material locations obtained from existing material records and the source from which they were obtained.

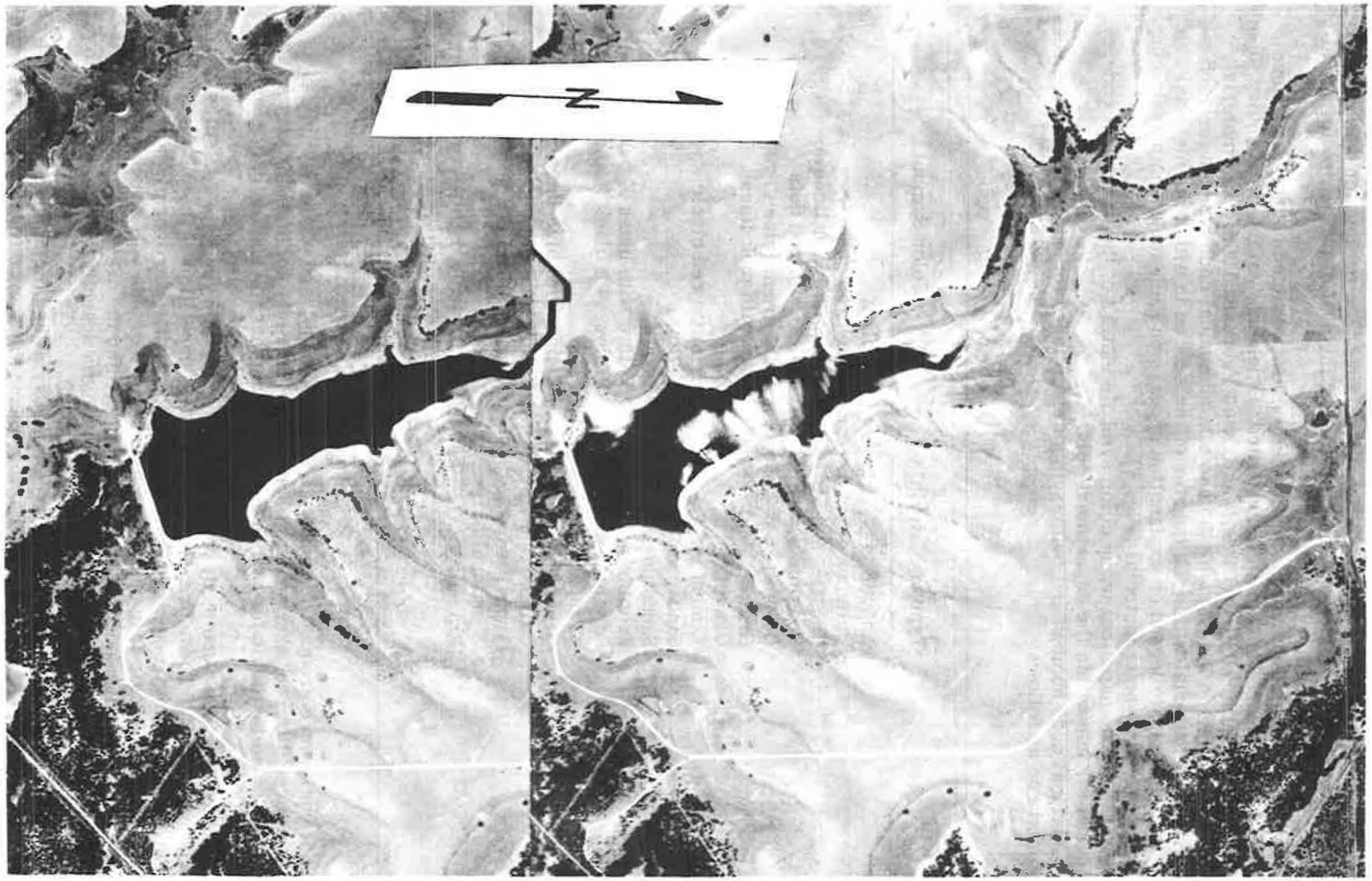


Figure 2. Aerial photographs in stereo pair of Section 12, T25N, R8E, and portions of Sections 11, 13, 14, T25N, R8E.

Type of Material	Oklahoma Emergency Relief Survey	Laboratory Soils Section	Laboratory Physical Section	Total No. Locations
Caliche	37	15	33	85
Chert	0	0	2	2
Conglomerate	0	0	2	2
Dolomite	0	0	33	33
Granite	0	2	35	37
Gravel	762	253	645	1,660
Limestone	9	118	204	331
Sand	552	68	373	993
Sandstone	11	34	203	248
Suitable soil	0	711	0	711
Sand and caliche	3	0	0	3
Asphalt sand (natural)	5	0	0	5
Rip rap	0	0	365	365
	1,844	1,208	1,895	4,947

FIELD DATA AND SAMPLING

This phase of the project involved three familiarization courses, a series of preliminary field investigations establishing a reconnaissance survey procedure, and scheduling the reconnaissance survey.

Familiarization Courses

The familiarization courses (Earth Resistivity Apparatus, Aerial Photo Interpretation, and Soils Mapping and Identification) were conducted by the Bureau of Public Roads and the Soil Conservation Service.

Earth Resistivity Apparatus.—R. Woodward Moore, Bureau of Public Roads, Washington, D. C., who works with the earth resistivity apparatus, visited the Materials Research Branch to teach the operation of the apparatus and how to analyze the data obtained. The equipment has not been purchased for use on the project.

Aerial Photo Interpretation.—An aerial photo interpretation school was conducted by Jesse R. Chaves of the Bureau of Public Roads, on July 15-22, 1959. The primary objective of the school was to familiarize personnel with techniques used in aerial photo interpretation to locate suitable materials used in highway construction (Fig. 2). Aerial photo interpretation has proved to be one of the more important as well as expedient means for a sufficient and thorough method for locating materials and an aid in estimating their quantities.

Soils Mapping and Identification.—A soil mapping and identification school was conducted by the Soil Conservation Service. The information acquired from this school was useful for the identification of soils and a knowledge of the terminology used with Soil Conservation Service Maps.

Preliminary Field Investigations

A series of preliminary field investigations was conducted in different areas of the State to establish a definite procedure for field reconnaissance surveying, to determine the accuracy of existing material records and of aerial photo interpretation, and to serve as a training program in identifying the different types of construction materials in the field.

A coded numbering system was established to enable each location containing material to be assigned a file number. By assigning a file number to each, it enabled the filing of these locations systematically and facilitated reference for detailed information. It also made it possible to record these locations by data processing machines. This file number, assigned by the reconnaissance party while in the field, is coded to indicate consecutively the county, type of material, site number, and the legal description of the location.

For example: File Number 01-05-09-07-18-24

The first two digits indicate the county. 01, Adair County

The second two digits indicate the type of material. 05, Dolomite

The third two digits indicate the site number. 09, the ninth dolomite location in Adair County

The fourth two digits indicate the section number. 07, Section seven

The fifth two digits indicate the township. 18, Township 18 north

The sixth two digits indicate the range. 24, Range 24 east

Field Reconnaissance Survey Procedure

The field reconnaissance survey procedure was divided into three segments (office preparation, field reconnaissance, and recording of information).

Office Preparation.--Office preparation included aerial photo interpretation, study of soil and geology maps, study of the existing materials, and gathering of any miscellaneous, pertinent data concerning the area to be surveyed.

With a knowledge of the geology and soils within specific areas, the potential locations of aggregates were determined by the technique of stereoscopic examination of aerial photos. The data contained within the existing material records were correlated with soil and geology maps to determine the availability of material from known sources. A study of the data indicated where there was a scarcity of material and served as a guide for locating new sources of material.

Field Reconnaissance.—Field reconnaissance included the investigation of areas that had been located during office preparation and from observation while in the field. Soil and geology maps, the data contained within the existing material records, and aerial photos were taken into the field for reference.

When material was located in the field, reference to soil and geology maps and aerial photos of the area usually denoted additional material locations.

Sand and soil suitable for stabilization were investigated with hand auger with a maximum depth of 12 ft or direct observation where possible.

Gravel was investigated by direct observation when possible and, if necessary, the area was noted to be extensively investigated by power drilling methods later.

Rock, such as sandstone and limestone, was investigated by direct observation of the outcrop, or if necessary, the area was noted to be extensively investigated with power drilling methods later.

An estimate was made as to the suitability of the material for specific uses. This was only an estimate based on personal judgment and confirmed by laboratory testing.

An estimate was made as to the quantity of material available. When it was impossible to make an estimate of the quantity, but it was obvious that more than 20,000 cu yd of material were available, the site was designated as having an "abundant amount," or if it was obvious that less than 20,000 cu yd were available, the site was designated as having a "limited amount."

Recording of Information.—Recording of the information was completed by the survey party in the field at the material site. All information was recorded on the reconnaissance field survey data sheet (Fig. 3).

Schedule for Reconnaissance Survey

A great deal of study was required to determine areas which best met the needs of the highway department. The first areas selected were, primarily, areas where material was more critically demanded due to proposed construction rather than areas of various degrees of scarcity.

A program of proposed construction projects was introduced by the department in

November 1959. The program included the interstate system and one hundred various extents of proposed construction of primary and secondary roads throughout the State. Reconnaissance survey was scheduled for these localities of new construction and has been completed.

The area surveyed for the proposed construction was limited to ten miles each side of the centerline if there was a scarcity of material. If the quantity of material was abundant in a particular locality, only the amount required for the proposed construction was located.

The schedule for reconnaissance survey that is presently being used is based on a study of the Oklahoma Department of Highway's Roadway Sufficiency Rating Report of 1960. The extents of roadway with a basic sufficiency rating of 79 or less were listed by county, by the total linear and vehicle-miles of State highways, the total of linear and vehicle-miles of U.S. highways, and the combined total of linear and vehicle-miles of State and U.S. highways occurring in the county. The vehicle-miles were determined by the product of the average number of vehicles traveling the extent of roadway per day

Form D-1 June 1, 1959
Materials Inventory
Research Project
Revised 5-20-60

RECONNAISSANCE
FIELD SURVEY DATA SHEET

FILE NUMBER 57-08-04-12-25-08

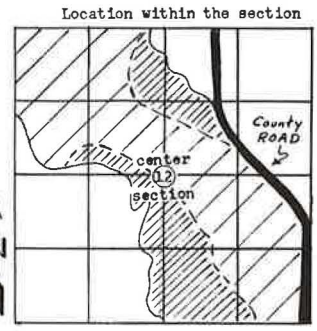
DATE 6/8/62

SURVEYED BY Mitchell Smith

LOCATION SW¼SE¼/S½SE¼NW¼/E½NE¼NW¼ Sec. 12 T 25 N R 8 E

DESCRIPTION OF LOCATION The area is located 2 miles west and South of Pawhuska, Oklahoma immediately North and East of Lake Pawhuska. The area is not Cultivated and is being used as Pasture.

Location within the section



POSSIBLE USES: SUBBASE ☐ BASE ADMIX ☒ CONCRETE SAND ☐
CONCRETE AGGREGATE ☒ RIP RAP ☒ SOIL ASPHALT ☐
SOIL CEMENT ☐ HOT SAND ASPHALT ☐ SAND CUSHION ☐
ASPHALT SURFACING ☒ OTHER

RATING OF THE MATERIAL: GOOD ☒ FAIR ☐ DOUBTFUL ☐

ESTIMATED QUANITY OF MATERIAL: ABUNDANT ☒ LIMITED ☐

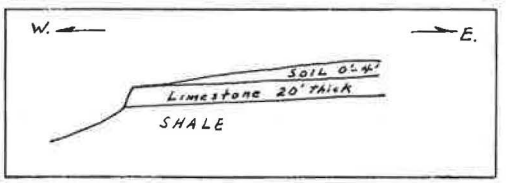
ESTIMATED QUANITY OF MATERIAL: 2,700,000 cu. yds.

DEPTH OF OVERBURDEN 0-4 ft. DEPTH OF MATERIAL 20 ft.

DESCRIPTION OF OVERBURDEN Soil Overburden ranging From 0 feet to 4 Feet in depth where Material probably would be quarried, and increases with depth away from the exposure of limestone.

DESCRIPTION OF MATERIAL Limestone - Approximately 20 feet thick. The limestone is very hard and Dense; Blue-Gray in Color. The limestone is deposited in layers ranging From one to two feet Thick with vertical jointing being Prominent. Material that would be detrimental, if used with the limestone for Concrete Aggregate, is present in the jointings and seams.

CROSS SECTION OF THE AREA (Give dimensions):



AERIAL PHOTO NO. DWK-12N-117 9/22/54

SAMPLE TAKEN ☒ YES ☐ NO

LAB. TEST NO. 63964

REMARKS The detrital material occuring in the jointings and seams of the limestone must be removed before the limestone is used for concrete aggregate. The limestone must meet Oklahoma Dept of Highways specifications before used. The limestone is named the Deer Creek limestone.

*File Number - The file number indicates, consecutively, the county, the type of material, the pit number, and the legal description of the area.

TYPE OF MATERIAL NUMERICAL CODE

Anhydrite	- 01	Congl't.	- 04	Gravel	- 07	Sandstone	- 10	Gravel and Sand	-13
Caliche	- 02	Dolomite	- 05	Limestone	- 08	Suitable Soil	- 11	Caliche and Sand	-14
Chert	- 03	Granite	- 06	Sand	- 09	Suitable Soil & Sandstone	- 12	Asphalt Sand	-15
								Rip-rap	-16

*EXAMPLE OF FILE NUMBER: 01-05-09-07-18-24

First two digits - 01 the county.....Adair County (Refer to County Code System)
Second two digits - 05 the type of material.Dolomite(Refer to Type of Material code no.)
Third two digits - 09 the pit number.....9th dolomite pit in Adair County
Fourth two digits - 07 the section.....Section no. 7
Fifth two digits - 18 the township.....Township 18 north
Sixth two digits - 24 the range.....Range 24 east

Figure 3.

and the mileage length of the extent of roadway. Approximately 5,000 linear miles of various extents of highways are listed in the present reconnaissance schedule. The reconnaissance survey is scheduled to give priority to counties having the largest total of vehicle-miles per day with a sufficiency rating of 79 or less. If a particular portion or complete county has previously been surveyed, that area has been eliminated from the schedule.

LABORATORY TESTING AND ANALYSIS OF MATERIALS FOR POSSIBLE USE

Laboratory testing pertaining to the field reconnaissance surveying has been kept to a minimum. The material was judged by experienced personnel who conducted the field reconnaissance survey. Samples of borderline materials were obtained and laboratory analysis made to determine their suitability. Material located by reconnaissance survey methods was considered only as potential material and laboratory analysis was required before the material was used.

CONSOLIDATION AND FINAL REPORT

The final report on the project is only in a prospective period at this time, but it will probably be used in conjunction with previously published data and will include the availability of materials within the total area of the State.

A progress report of potential material sites was published in April 1961. The publication is titled "Oklahoma Materials Inventory Research Project Verified and Non-Verified Potential Material Sites, April 1961 Edition." The publication included potential material sites located during the library study phase of the project, which are termed non-verified, and potential material sites located during reconnaissance survey, which are termed verified.

All the material sites were recorded by electronic data processing machines. Pertinent information relating to each listed material site was published, such as the county, type of material, pit number, location (legal description), usability, quantity, depth and type of overburden, owner (private, commercial, or government), laboratory number and date sampled, and if the material site was verified or not verified.

Three maps have been prepared from the results of the data obtained from the reconnaissance survey. The maps indicate the geographic location of potential material sites for a particular type of highway construction. The maps designate, respectively, materials suitable for hot sand asphalt base course construction, stabilized aggregate base course construction, and coarse aggregate for portland cement concrete construction. A radius of 15 miles is drawn around the material sites. The radius represents an economically feasible distance allowed for the hauling of the material, and indicates that particular type of material is available within its boundaries. Copies of these maps have been made and distributed to the various branches within the highway department. As more data are obtained from field reconnaissance, the maps will require revision. This location of additional material sources could reduce the maximum haul below the 15 miles used at the present time.

Approximately 21,000 sq mi or 31 percent of the total area of the State has been surveyed since the project was initiated. The areas surveyed are indicated geographically on a sectionalized State map, titled "Reconnaissance Survey Work Record." Approximately $54,000 and 85 man months of work have been used to date.

ACKNOWLEDGMENTS

To conduct a research project requires the willing cooperation, support, and contributions of several people with knowledge and experience in various fields of study.

The author gratefully acknowledges the supervision of R.A. Helmer, Research Engineer. His devotion and wisdom in highway research and his distinguished work in the Oklahoma Department of Highways are reflected in his continued concern that the results of research by his staff be made available to all.

Acknowledgment is in order for the research personnel who are contributing their efforts to the project. Also, appreciation is extended to the U.S. Bureau of Public Roads, for without their cooperation and advice, the project would not be possible.

Arizona Materials Inventory Reports

LEWIS E. SCOTT, Engineering Geologist, Arizona Highway Department

This paper presents a description of the form and content of the Arizona Materials Inventory reports. Each report covers one of 14 Arizona counties that range in size from approximately 1,400 to nearly 10,000 sq mi. These are subdivided into map sheet areas averaging 30 by 36 mi. A pit and quarry map locates all known sources by serial number and appropriate symbol. A photogeologic map shows the relationship of the sources to the surface geology. A data sheet lists all sources in the area by serial number and describes location, type of material, mechanical analysis, and evaluation of each.

The reports are technical, but are written so that they may be used by the non-engineer or geologist materials prospector.

•TEN to fifteen years ago a few States had found that a highway materials inventory was a useful tool in the systematic location of materials sources. Use of this tool developed slowly until the mid-1950's when the demands of the Interstate Highway program made an inventory a virtual necessity. The huge increase in mileage due to the new program in addition to the accelerating normal program made the location of adequate materials sources a real problem. To develop these new sources rapidly required that all existing pits and quarries be reviewed to determine how many had been exhausted or lost and what quantities and types of materials remained. Once plotted, this information is important to nearly all phases of highway planning, design, construction and maintenance.

The value of the inventory is twofold. The initial result is that any lack of either quantity or type of construction materials in a given area is readily apparent. An accurate knowledge of the quantity, type and location of available materials is essential to planning and design. Without it a proposed route may have to be delayed until the design can be adjusted to fit the existing supply. If these factors are ignored, the added costs of excessive haul distances are a certainty. By contrast, a review of all known sources often reveals the presence of a large, low grade source that can be judiciously used or upgraded at considerable savings. This not only affects economy but also conservation of high grade materials which even now is becoming an important factor in many places.

Once the areas deficient in either type or quantity of materials are indicated, the inventory can also act as a guide for prospecting for the required sources. This is particularly true if the inventory mapping includes surface geology. Barren or unlikely areas can be quickly eliminated and the prospecting concentrated in more promising areas. The recording of all test data also eliminates duplication of work, either at the same site or over the same area looking for a different type of material.

INVENTORY METHOD

Basically, a highway materials inventory consists of assembling all available information on all known materials sources and recording these data in a useful form. Usually this is done by plotting the numbered sources on a map and summarizing the laboratory and field testing results on a data sheet. These are customarily combined to form a folio or report.

Paper sponsored by Committee on Surveying, Mapping and Classification of Soils.

From this framework is developed the form of the inventory best suited to local needs. Certain types of information are stressed. The breadth of coverage is designed to shape the report to the purpose intended, which in Arizona is to provide detailed information on the location and test results of all sources by county as well as by their relationship to surface geology.

This broad coverage, rather than strip maps, is used because of the availability of base maps on county units and the desire to show the relationship between the materials sources and the surface geology. Sand and gravel are used primarily as construction materials in Arizona, so that base maps covering a large area are desirable to show the stream pattern to indicate the origin and therefore the general composition of the alluvial deposits.

Materials sources in Arizona are developed from the central Materials Division office by seven field crews working under the supervision of two materials field engineers. The list of future projects scheduled by the Plans Division is used to program the work, each foreman being assigned several projects suitable to his type of equipment in a general area. The plan and profile of a given project are studied in the office by a field engineer to determine the materials and design requirements. If the materials file shows nearby existing sources, they will be retested and enlarged if necessary. If no suitable sources exist, the quantity and desired location of materials needed are given to the exploration foreman to investigate along with the required centerline testing. When the drilling, test pitting and sampling on the pit areas and centerline are complete, the field engineer inspects the work noting soils, rock, and terrain features to classify excavation for design purposes. When the laboratory tests on the proposed materials sources are completed the boundaries of ample suitable material are established, the sources are assigned pit serial numbers and are then, hopefully, sent on for acquisition. Often geological and aerial photo studies are made to locate sources, and the testing augmented or directed by geophysical studies.

Data on all known materials sources are filed in the central Materials Divisision office. Each source is identified by a serial number assigned chronologically after testing and approval. The folder on each source contains a pit sketch map showing the pit boundaries, any test holes, the haul road, and the surveyed tie to highway stationing. The legal description and plat and all laboratory test results are included. This information is cross-filed by serial number and by project. The location is also plotted on a highway index map for rapid location.

This reservoir of data supplies nearly all the materials information needed to make a materials inventory. Of only slightly less importance is the availability of a suitable base map on which these data can be plotted. By good fortune, the Photogrammetry and Mapping Division of the Arizona Highway Department is currently revising the statewide General Highway Map series on a county basis. These extremely accurate maps are made photogrammetrically from 1953 Army Map Service aerial photography and U. S. Geological Survey and U. S. Coast and Geodetic Survey control. The basic unit is a lithographed map sheet covering an area of approximately 30 by 36 mi at a scale of ½ in. = 1 mi. Each county series or folio contains from 2 to 22 map sheets, depending on area. To date, maps for Maricopa, Santa Cruz, Gila, and Pima Counties have been completed in that order, covering the south-central portion of the State.

These maps can be produced at the rate of only one to two counties per year. Maps of the first three counties had been or were being published when the materials inventory began so that no delay was experienced until recently. Publication of the Pima County materials inventory report was delayed several months waiting for maps, and it is now evident that future inventory work can proceed only at the pace set by the Photogrammetry and Mapping Division.

The materials inventory and the published reports are made by the Engineering Geologist of the Materials Division who is assigned to the project permanently. This work is under the general supervision of the Engineer of Materials. Until recently a geological assistant was also assigned to the project but was reassigned when it became evident that the program would have to adopt a much slower pace. As is the case with most other States making an inventory, this work is being done in Arizona

in cooperation with the U.S. Bureau of Public Roads and is supported, in part, by the 1½ percent (HPS) funds. These funds have purchased a complete set of aerial photographs giving statewide coverage and are also used for salaries, travel expenses and publication costs.

DESCRIPTION OF REPORT

The materials inventory reports are published as a folio 14 by 17 in. in size bound along the left edge with a plastic multi-ring binder. All printing is done by Highway Department facilities using the offset method. The large size was chosen for two reasons: large maps give a continuity for study of the relationships between the surface geology and the materials sources; and the annoying folding and unfolding of maps is eliminated.

The reports contain the following sections, given in order: Introduction, Geologic History, Map Sheet Groups, and Appendix. Of these, the map sheet groups are the most important as they contain the locations, descriptions, and test data. The other sections are essentially explanatory to aid in the use or explanation of the technical data.

Introduction

This section describes the contents of the report and their purpose. Brief descriptions of the geography of the county and the general type of materials used are included. The explanation of the method of preparation of the report goes into some detail so that the reader may judge the accuracy and validity of the data included.

Geologic History

This section is important and probably the most difficult to prepare. Its purpose is to give the reader a concise background of the geologic processes forming the topography of the county and the sequence of the rock strata. This background information is intended to explain the origin of the materials in known sources as well as to provide a basis on which new sources can be located by deduction. Care is taken to make this information technically accurate, but in non-technical terms where possible. It has been found that most engineers and materials prospectors are interested in this information and are by nature observant. A surprising number have formed their own theories to guide them in field exploration.

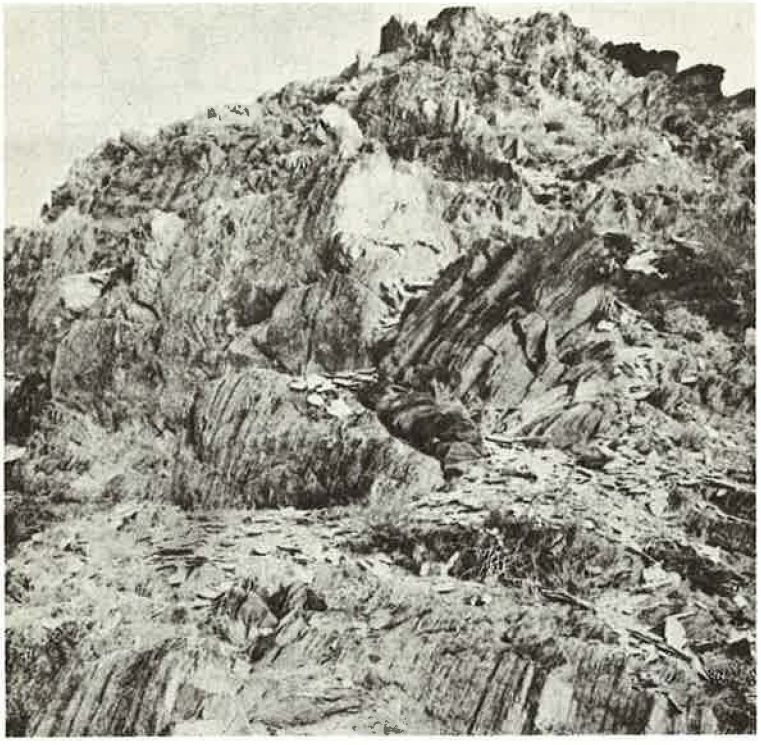
To supplement the written history, one or more geological cross-sections are given on the facing page to clarify the relationship and location of the formations described.

A subsection gives brief descriptions of the geologic formations mapped on the following geological maps. These descriptions are given under the identifing map symbol and describe the type of formation, the color, size, or appearance characteristics, and contain a special note as to what kind of mineral aggregate will be derived from it. An opinion is included as to probable plasticity and quality of the fines. These descriptions provide enough information so that the major units can be recognized in the field. To aid in recognition, a series of large photographic illustrations of the more important formations are included in the map sheet groups. The captions point out the recognition features noted in the formation descriptions (Fig. 1).

Map Sheet Groups

As previously noted, this section contains all the data on the location, and tests of the materials sources in the county covered by the report. This information is given on a pit and quarry map, geological map and test data sheets. Included are the photographic illustrations described in the previous section. Each group consists of one map sheet area so that a report will contain two or more groups to cover the entire county that is the subject of the report.

The base maps used for both pit and quarry and geological maps are 18- by 24-in., map sheets published by the Photogrammetry Division to the scale of ½ in. = 1 mi.



Schist – mapped as Sch, one of three oldest rocks in the State (Pre-Cambrian). Thin, even layers or lamina are characteristic. Lamina are usually flat, but are here faulted into a vertical position. Formed by heat and pressure from shales or volcanic rocks. Forms light-colored hills.

Figure 1.

These contain the stream and drainage pattern, transportation routes, and hatched locations of the higher mountain areas.

All known materials sources in a given map sheet area are plotted on the pit and quarry map (Fig. 2) using appropriate symbols to designate the type of material and ownership. A black round dot indicates mineral aggregate (MA) or aggregate base (AB). A vertically divided, half black, half white round dot represents a source of select material. The round dots indicate only sources owned or controlled by the Arizona Highway Department. Solid and divided square dots for the same materials indicate Federal or county ownership. Commercial sources are marked by a round dot divided into quarters. Because borrow material is usually available on each project as needed, all symbols designating it are circular. These contain a number from one to seven denoting quality of the material based on the Arizona Highway Department base thickness chart of 1959. These ratings are: 1-2-3, good; 4-5, fair; 6-7, poor. Any exhausted or depleted pit or quarry is marked by a circled M indicating "mined out." All sources are identified by serial numbers placed beside or below the source symbol on the map.

The geology map (Fig. 3) for the same area is made on an identical base map. The larger rock exposures and outcrops are identified by the standard formation name abbreviation and a geometric pattern which is printed in color for clarity and emphasis. The younger alluvial deposits are identified by name abbreviation only for the sake of simplicity. The major faults in the area are shown, but otherwise no structural features are included. The larger rivers, washes and intermittent streams are marked by a gravel or dotted pattern denoting a usable quantity of granular material. Symbols

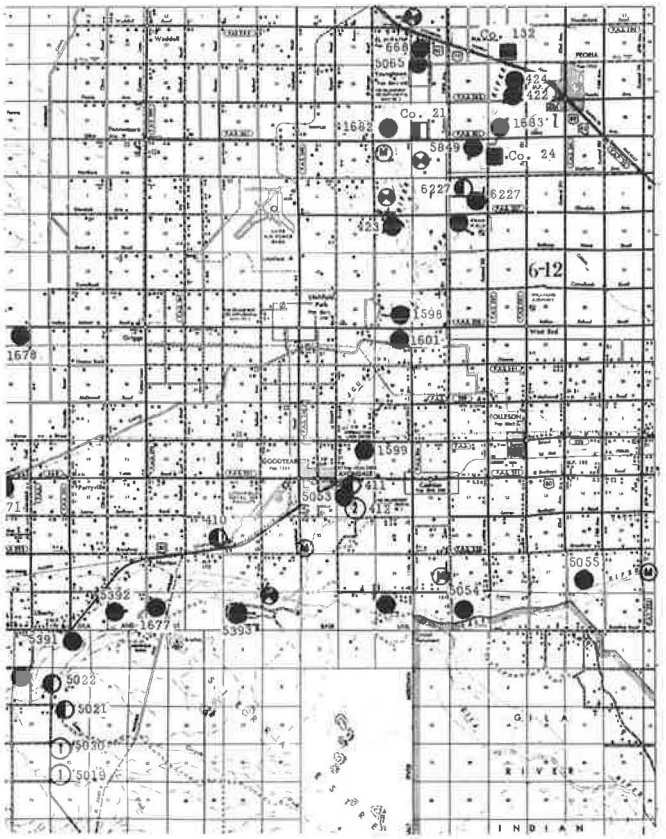


Figure 2. A portion of the pit and quarry map.

on this pattern identify various types of material which are explained in the legend. The mapping of the geological formations and the stream pattern to this point is done from interpretation of aerial photographs and use of existing geological and soil survey maps. This information is then checked in the field with particular attention to the type and origin of gravels in the stream channels and the formational limits. This checking is detailed along highways in the area, but is less thorough in mountainous or inaccessible areas where terrain and distance make location of new materials sources unlikely.

At this stage the materials source locations from the pit and quarry map are marked on the geologic map by a donut-shaped universal symbol. The sources are field checked to see if they still exist, to estimate the amount of material still available, and to check the accuracy of the location marked on both maps. In the report, the pit and quarry and the geological maps are on facing pages for easy reference and comparison. In later reports a 6-in.-wide stub page is bound between them giving the legend for the geologic map on one side and the explanation of the materials source symbols on the other. The proper side is face up as it is turned to clear one map or the other.

The data sheet (Fig. 4) contains the location and test information of the sources shown on the pit and quarry maps. Each pit and quarry map in each map sheet group is accompanied by at least one data sheet. As a rule all the sources shown on a pit and quarry map can be listed on a single 26-line data sheet. Exceptions are map sheet areas containing several major highways or urban areas, which may require up to six data sheets to describe the large numbers of sources customary in these areas.

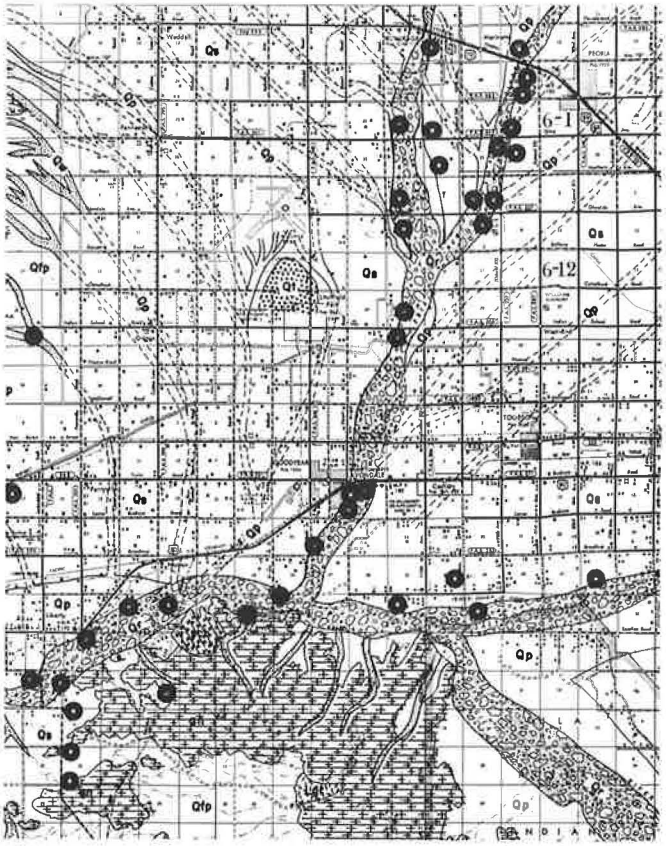


Figure 3. A portion of the geology map.

The data sheet is the heart of the inventory report. It presents a summary of the laboratory and field information on file in the central office on each source shown on the pit and quarry map. This information is shown in the form of a table in vertical columns grouped into three sections. All information on each source, identified by the pit serial number, is shown on one horizontal line. The location section gives the legal description, highway number, project number, and stationing on the project. The type of material section notes whether it is sand, gravel, rock or clay; the use for which it is intended and was tested, as well as an estimate of the yardage available. The Atterberg limits, sieve analysis and AASHO soil group are given for a representative sample from each source. Succeeding columns give the averages of the plasticity index and percent passing the number 200 sieve for all samples tested from the source. Also, the quality of the source from poor to excellent, is judged from the information on file or field inspections and given in the last column. Where no laboratory test data are available in the materials or project files the locations and type of material information is given and the words "No Data Available" are written across the test data columns. This allows the source to be located in the field where some estimate of quality can be made by eye.

Appendix

This final section contains explanatory charts and maps for reference. The pages of the appendix are not shown in this paper, but some features warrant discussion. The page on Standard Specifications of the Arizona Highway Department is intended for reference by municipal, county or Federal personnel using the report. Current

TEST DATA SHEET
MAP SHEET NO. 8

NOTE: A.B. – AGGREGATE BASE. M.A. – MINERAL AGGREGATE. S.M. – SELECT MATERIAL.

LOCATION							TYPE OF MATERIAL			TEST DATA													QUALITY
LEGAL DESCRIPTION			PIT NUMBER	PROJECT NUMBER	ROUTE NUMBER	PIT LOCATION BY STATION	PROPOSED USE OF MATERIAL	EST. QUANTITY CU/YD	KIND OF MATERIAL	REPRESENTATIVE SAMPLE									AVERAGE OF TESTED SOURCE				QUALITY OF MATERIAL (FOR USE LISTED.)
										HOLE NUMBER	DEPTH OF SAMPLE	ATTR'BG LIMITS		SIEVE ANALYSIS % PASSING					A.A.S.H.O. SOIL CLASSIF.	DEPTH OF SOURCE	AVERAGE OF VALUES		ABRASION 500 REV	
TOWNSHIP	RANGE	SECTION										L.L.	P.I.	#200	#40	#10	1/4"	1"			P.I.	% MASS #200		
2S	4W	23	1527	FI-159(1)	U.S.80	2200'Lt.Sta.6230	Select	35,000	Sand, Gravel	4			NP	2	10	47		95	A-1-a	0	0-2	0-4	32	Good
3S	4W	11	1526	FI-159(1)	U.S.80	600'Rt.Sta.6057	Select	11,000	Sand, Gravel	3			NP	6	20	50		99	A-1-a	0	0-4	2-37		Good
3S	4W	14	1525	FI-159(1)	U.S.80	4700'Rt.Sta.5979	AB/MA	20,000	Sand, Gravel	1			NP	6	17	43		96	A-1-a	2	0-1	2-16		Good
5S	4W	33	1503	FI-159(1)	U.S.80	1400'Rt.Sta.5210	AB/MA	60,000	Sand, Gravel	6			NP	6	24	50		85	A-1-a	0	NP	2-9	29	Good
5S	5W	35	510	FI-156	U.S.80	700'Lt.Sta.5026	Select	7,000	Sand,Gravel	4			NP	12	32	56		88	A-1-a	2	NP	2-31		Good
6S	2W	19	5610	I-0022(7)	St.84	1000'Rt.Sta.654	AB/MA	50,000	Sand, Gravel	5			NP	5	20	48		91	A-1-a	0	NP	1-17	31	Good
6S	2W	20	5612	I-0022(7)	St.84	1700'Rt.Sta.743	Select	27,000	Sand, Gravel	2			NP	4	16	48		91	A-1-a	0	NP	1-10	34	Good
6S	2W	35	5617	I-0022(7)	St.84	2300'Rt.Sta.500	AB/MA	80,000	Sand, Gravel	3			NP	3	15	48		96	A-1-a	0	NP	1-8	35	Good
6S	3W	7	5642	I-0022(8)	St.84	2640'Rt.Sta.360	Select	38,000	Gravelly sand	5			NP	6	23	54		94	A-1-a	0	NP	4-14		Good
6S	3W	14	5648	I-0022(13)	St.84	800'Rt.Sta.563	Select	48,000	Gravelly sand	9			NP	6	22	59		92	A-1-a	0	NP	2-15		Good
6S	3W	15	5646	I-0022(13)	St.84	300'Lt.Sta.514	Select	53,000	Gravelly sand	6			NP	4	19	52		89	A-1-a	0	NP	2-33		Good
6S	4W	34	5637	I-0022(8)	St.84	4 Mi.S.Sta.202	AB/MA	73,000	Sand, Gravel	13			NP	12	25	46		82	A-1-a	0	NP	3-24	28	Good
7S	1W	5	5625	I-0022(7)	St.84	2000'Rt.Sta.1070	Select	50,000	Sand, Gravel	6			NP	4	18	49		92	A-1-a	0	0-2	1-17	32	Good
2S	4W	35	1532	FI-159(1)	U.S.80	600'Rt.Sta.6174	Borrow	20,000	Clayey sand	5		7	11	29	43	68		99	A-2	0	6-13	10-44		Fair
3S	4W	3	1527	FI-159(1)	U.S.80	700'Lt.Sta.6091	Borrow	20,000	Silty sand	2			6	23	38	66		100	A-1-a	0	2-7	0-40		Good
3S	4W	10	1528	FI-159(1)	U.S.80	500'Lt.Sta.6019	Borrow	18,000	Gravelly sand	4			2	15	30	54		100	A-1-a	0	0-3	8-17		Good
3S	4W	26	1522	FI-159(2)	U.S.80	700'Rt.Sta.5899	Borrow	15,000	Gravelly sand	2			4	19	34	55		100	A-1-a	0	0-4	12-30		Good
3S	4W	34	1520	FI-159(2)	U.S.80	800'Lt.Sta.5840	Borrow	15,000	Gravelly sand	2			6	19	31	55		98	A-1-a	0	3-9	17-23		Good
4S	4W	11	1515	FI-159(2)	U.S.80	1000'Rt.Sta.5735	Borrow	15,000	Sand, Gravel	3			NP	8	22	48		90	A-1-a	0	0-2	2-12		Excellent
4S	4W	26	1514	FI-159(2)	U.S.80	600'Rt.Sta.5568	Borrow	20,000	Gravelly sand	No data available														
5S	4W	2	1509	FI-159(3)	U.S.80	600'Rt.Sta.5482	Borrow	18,000	Gravelly sand	2			NP	22	43	66		99	A-1-a	0	NP	16-28		Excellent
5S	4W	10	1510	FI-159(3)	U.S.80	600'Rt.Sta.5429	Borrow	20,000	Gravelly sand	4			NP	17	32	70		100	A-1-a	0	NP	15-24		Excellent
5S	4W	28	1504	FI-159(3)	U.S.80	600'Rt.Sta.5251	Borrow	20,000	Gravelly sand	3			NP	17	36	59		94	A-1-a	0	NP	8-17		Excellent
6S	2W	20	5611	I-0022(7)	St.84	400'Lt.Sta.6901	Borrow	80,000	Sand, Gravel	4			4	10	18	47		99	A-1-a	0	2-4	6-28		Good
6S	2W	36	5620	I-0022(7)	St.84	900'Rt.Sta.9631	Borrow	85,000	Sand, Gravel	4			6	9	21	47		90	A-1-a	0	0-15	9-53		Good
6S	3W	16	5645	I-0022(13)	St.84	600'Rt.Sta.4581	Borrow	90,000	Gravelly sand	5			NP	9	33	62		90	A-1-a	0	NP	4-11		Excellent

Figure 4.

specifications for mineral aggregate, aggregate base, and select material are listed. The quality of a source noted in the report is based on these specifications and therefore it may be entirely suitable under looser specifications or for another purpose.

An explanation of the serial or pit number system is also included for the information of the non-highway department user. A table showing the date each hundredth serial number was assigned is given so that rough dating of the prospecting and testing is possible without access to the central file records.

An AASHO subgrade classification chart is printed on the facing page to show the origin of the group index figures given on the data sheets. By checking the soil group against the chart further information on the type or character of the material may be obtained.

The aerial photo index is intended to provide a quick method to locate the aerial photos needed for more detailed study of any part of the pit and quarry or geological map areas. Flight lines are plotted across an outline of the county with the flight and photo numbers noted at each end of the line at the county boundary.

Topographic map coverage of the same county is plotted on an identical outline. The outline of U. S. Geological Survey quadrangle sheets are dashed in to scale on the outline and identified by name and date. This index is also intended as a quick source of further information for detailed or additional study in the area.

COVER

With the exception of the first report, the cover has consisted of a margin-to-margin photograph on which the black title is overprinted. The photograph used is an aerial or distance view of some prominent geological feature of the county covered by the report. It is printed in one color on white cover stock to make the report more attractive and to aid in identification.

The title format overprint is standard to all reports to indicate each is only one segment of the statewide inventory. The county name varies but its size and position penetrating the State outline is constant. This overprint and the plastic binder are black to set off the colored photograph.

USE OF REPORT

Distribution of the materials inventory reports is restricted to engineering personnel of the Arizona Highway Department. They can be issued to engineering personnel of Federal or municipal agencies and have been sent to out-of-state highway departments or universities when requested. This restriction is necessary to protect many of the sources listed that are not owned and controlled outright by the highway department. Because 86 percent of Arizona land is owned by Federal, State, or local government units, most of the sources are used on a permit granted for a definite period of time of either months or years. Those sources on private land are used on a royalty basis. Because permits expire or can be assigned to others, the restriction of the reports containing locations and test results is necessary to protect the investment of time and money used to develop them. In or near population centers this problem is acute because of competition for sand and gravel and is only slightly less in areas of scarcity. It is unfortunate that information gathered by a public agency must be withheld from the public but in this case the saving of tax dollars seems to justify.

Countrywide Survey of Maximum Highway Subgrade Saturations in India

H. L. UPPAL, Assistant Director, Central Road Research Institute, New Delhi, India

According to the standard method, the design of a road or runway pavement is carried out at saturated conditions of the subgrade. The thickness thus determined will be uneconomical if the subgrade is not likely to be saturated in actual practice. It is, therefore, necessary to know the degree of saturation to which the subgrade is wetted during the worst part of the year so that the design at that particular moisture (but not higher) is carried out. With this object in view a countrywide survey was carried out to find out the degree of saturation of the subgrade (mostly under flexible pavement, which forms bulk of the road mileage in the country) at the time of recession of the monsoon when subgrade moisture conditions are worst. The study indicates that the degree of saturation varies considerably and does not justify the design of pavement at 100 percent saturation of the subgrade at all places in India.

• ACCORDING TO standard practice, the thickness of a pavement is designed on the assumption that the subgrade will become completely saturated sometime during the year, even though it is known that such an assumption amounts to varying degrees of overdesigning, depending on the maximum degree of saturation that the subgrade in the area concerned is ever likely to undergo.

It is also known that in certain areas, complete saturation of the subgrade is never reached. In the U. K., for instance, it was established that in areas abounding in silty clays the maximum saturation that the subgrade can ordinarily attain is substantially below saturation, under a sealed surface. Consequently, for the area concerned, it has been laid down that the design of pavement is to be carried out at this particular moisture, called "equilibrium moisture content." This has resulted in reducing the designed thickness of pavements appreciably.

It is further known that the phenomenon of "equilibrium moisture" does not exist in tropical countries, due to wide variations in temperature conditions, etc. The prevailing practice in such areas is either to design as per standard practice by assuming complete saturation, or to combine standard design and experience, particularly in dry areas with low water tables, and to fix a thickness in between.

OBJECT OF THE STUDY

As the information on the subject of subgrade moisture in regard to India has an equally important bearing on the economic pavement design in that country, the present study was undertaken both with a view to make subgrade moisture data for India available to the various research organizations working on fundamental aspects of ground

Paper sponsored by Committee on Surveying, Mapping and Classification of Soils.

moisture movements, and also to obtain authentic data about the maximum subgrade moisture in different parts of the country, with a view to seeing if in certain areas not subject to complete saturation of subgrade the standard design can be justifiably modified with a view to rationalization, as well as economy, of design. The economics of the problem can be well realized from the fact that every inch reduction in the hard crust of the road pavement in India reduces the cost by about Rs. 2,000 to 3,000 ($420 to $630) per mile for 10-ft wide road.

FACTORS INFLUENCING MOVEMENT OF MOISTURE

As far as is known, the degree of saturation of a subgrade is dependent mainly on the rainfall and soil conditions of the area, and as such, for investigation, the country was divided into different zones on the basis of rainfall and soil type.

Rainfall

As a result of rainfall, the wetting of the subgrade under the sealed surface can take place in the following manner, to a large extent due to the proximity of the water table. The nearer the water table is to the subgrade, the lesser the negative pore water pressure, and consequently greater the moisture content, and vice versa. It is a common observation that the water table is lowest during the driest season and starts rising with the onset of the monsoon, and is highest just when the monsoon recedes. The subgrade under a sealed surface in an area with a low water table can still be wetted to a limited extent, due to the suction of moisture by the subgrade from the adjoining unsurfaced berms, wetted as a result of rainfall. The distance to which the moisture can travel in this way is limited to 2 to 3 ft (1) from the edge towards the center of the road. The actual moisture content will however depend on the intensity of the rainfall. It can, therefore, be assumed that, at a certain site abounding in a particular type of soil, the wetting of the subgrade is governed by the intensity of the rainfall, and therefore, one of the ways of dividing India into different zones for purposes of sampling would be on the basis of rainfall intensity. According to the Meteorological Department of India, the annual rainfall varies widely, but a general division into nine rainfall zones ranging from less than 10 in. to over 200 in. per year can be made. The various parts of India covered by each rainfall zone are shown in Figure 1.

Soil Type

Apart from the intensity of the rainfall another factor that greatly contributes to the variations in the moisture-holding capacity of the subgrade is the nature of the soil itself. It is well known that for the same water table, a clayey subgrade absorbs more moisture and will consequently have a lower bearing capacity than sandy soil. It will, therefore, be necessary to know the different soils of India. In the absence of a soil engineering map of India, use was made of the data collected as a result of soil survey carried out by the Agricultural Department. The nomenclature adopted in the agricultural map is such that most of the research workers in the soil mechanics laboratories are familiar with their corresponding engineering properties. According to this map there are 20 different types of soils in the country, 14 of which are shown in Figure 2:

1. Alluvial soils (undifferentiated).
2. Coastal alluvium (new).
3. Grey and brown soils of Indus, Jamuna, and Gangetic basin impregnated with salts.
4. Gangetic alluvium (calcareous).
5. Deep black or Regar soils of valleys.
6. Medium black soil of trap.
7. Shallow black soils.
8. Mixed red and black soils.
9. Red loam.
10. Red gravelly soils.

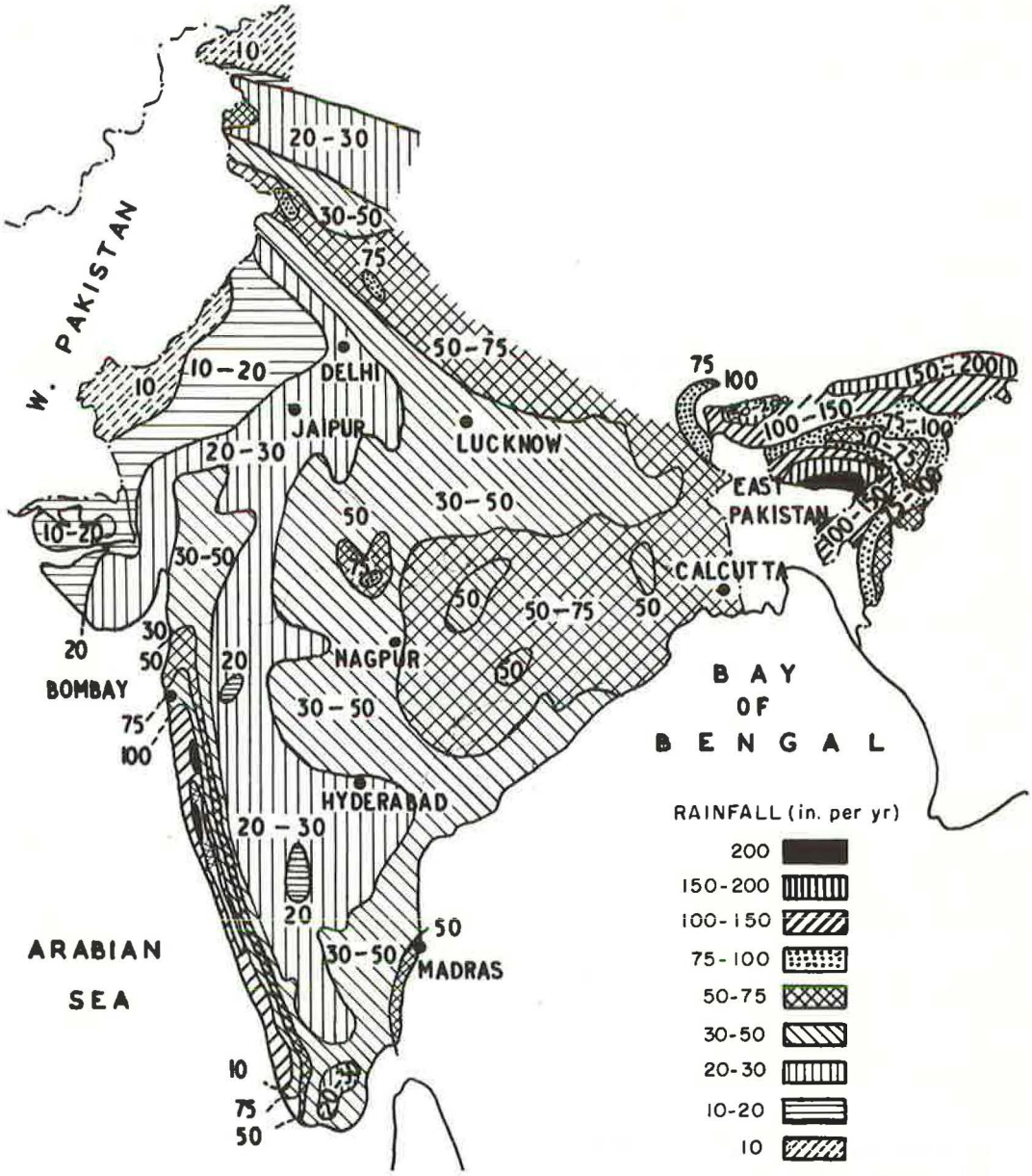


Figure 1. Rainfall map of India.

11. Red and yellow soils.
12. Laterites (high and low level).
13. Laterite soil (old alluvium).
14. Desert soils (grey and brown).
15. Saline and deltaic soils.
16. Skeletal soils.
17. Forest and hill soils (undifferentiated).
18. Sub-montane regional soils (undifferentiated).
19. Foot-hill swampy soils (undifferentiated).
20. Peat soils.

Climatic Conditions

The moisture content of an unsurfaced earth road is likely to be affected by the atmospheric temperature, relative humidity, etc., but the same factors are not likely to influence the moisture content of the subgrade under a sealed surface to any appreciable degree. This is particularly true at the time of recession of the monsoon, when the investigation was carried out. It was, therefore, thought unnecessary to consider this additional factor for subdivision of the country into different zones for purposes of this study.

It is admitted that there may be factors other than those mentioned (such as the situation of a particular area in a certain terrain or general drainage conditions) which would also affect wetting of the subgrade, but taking into consideration the size of the country (covering about 1.27 million square miles), the local conditions of a particular area that may be limited to a small patch had to be ignored in a study of this type.

Division of the Country

Figure 1 shows that, though there are nine rainfall zones in the country, the area covered by zone with rainfall more than 200 in. annually is very small; therefore, for purposes of the present study the remaining eight zones only have been considered. Similarly, there are 20 different types of soils as shown in Figure 2, but soils designated as (a) saline and deltaic soils, (b) skeletal soils, (c) forest and hill soils, (d) sub-montane regional soils, (e) foot-hill swampy soils, and (f) peat soils are minor in the sense that they cover only a small area; therefore, in the present study, only the remaining 14 soils have been considered.

If the rainfall map is superimposed over soil map, it will give approximately 35 zones which will cover all combinations of soil types and rainfall intensities. An idea of the various parts of the country covered by such zones can be gained from the appendix which indicates the name of important cities in each zone.

SAMPLING AND TEST PROCEDURES

Roads

The selection of an actual road for purposes of present investigation within the zone itself was left to the Chief Engineer of the State concerned. It was intended that the road proposed by the State should be such that it does not lie on a very high embankment, does not have poor side drainage, or is not subjected to flooding. This was done with the object of eliminating as many variables as possible, so that the study of movement of subgrade moisture could be restricted to the water table, as a result of rainfall and soil type only. The location of road sites selected for investigation is shown in Figure 3. Because the concrete road mileage in the country is very significant, the selection of roads was restricted to flexible pavement with a bituminous surface only. The thickness of the road crust generally varied from 10 to 12 in.

Airfields

Because the information about the bearing capacity of subgrade is equally important for the design of runways, the present study was extended to the civil runways also.

TABLE 1

DEGREE OF SATURATION AND CONSISTENCY LIMITS OF SUBGRADE SOILS FROM VARIOUS SITES

Type of Site	State	Site No.	Station	Location	Approx. Water Table (ft)	Degree of Saturation (%)					Consistency Limits of Soil		
						Surface 2 In.	First Foot	Second Foot	Third Foot	Bottom 2 In.	Liquid Limit (%)	Plas. Index (%)	Sand Content
Road	Jammu & Kashmir	1	Jammu	Jammu Miran Sahile Road, mile 5	18	25.65	27.98	31.78	33.05	33.97	23.4	8.7	29.0
		2	Srinagar	Srinagar Jammu Road, mile 11	10	77.22	82.43	84.09	88.58	84.93	46.3	22.6	2.3
	Punjab	3	Amritsar	G. T. Road, mile 275	6.5	79.90	80.52	87.05	92.35	92.35	26.6	10.7	16.6
		4	Bhatinda	Surnam Bhiki, Bhatinda Road, mile 99	80	15.93	20.60	26.83	37.42	38.83	24.1	7.2	35.4
		5	Hissar	Delhi Hissar Submanki Road, mile 99	-	19.34	19.03	20.61	20.01	21.51	28.1	12.0	17.1
		6	Jullundur	G. T. Road, mile 223	22	28.63	36.03	35.04	33.18	33.69	24.8	10.8	44.0
		7	Karnal	G. T. Road, mile 77	10	41.60	47.01	50.29	62.53	69.09	28.8	13.0	11.3
		8	Patiala	Patiala Nabha	12	21.55	23.70	24.57	25.43	25.86	22.9	7.2	70.5
	Rajasthan	9	Ajmer	Mangliwar-Pisan-Gunj Road mile 12	-	37.62	39.83	38.21	31.59	31.18	29.5	12.7	42.2
		10	Jaipur	Jaipur-Ajmer Road, mile 6th Jaipur	60	9.91	13.48	13.81	13.20	14.62	21.2	3.8	68.4
		11	Jaisalmer	Pokaran-Jaisalmer, Road mile 63	-	18.91	22.06	20.28	21.22	21.22	22.6	6.8	64.0
		12	Jodhpur	Jodhpur-Patti Road, mile 7th	15	5.26	6.48	6.68	8.77	8.77	23.1	8.2	71.0
	Madhya Pradesh	13	Betul	Betul-Nagpur Road, mile 56	-	79.45	81.93	84.42	81.87	83.80	57.9	30.1	5.7
		14	Bhopal	Bhopal-Sehore Road, mile 4th	8	95.48	93.44	94.46	95.90	98.81	57.5	22.4	20.0
		15	Bilaspur	Bilaspur-Mandla Road, mile 3rd	4	46.02	48.17	51.98	55.80	58.59	57.2	27.4	7.2
		16	Gwalior	Gwalior-Jhansi Road, mile 4th	30	72.42	74.20	73.61	80.47	89.69	31.3	14.2	12.0
		17	Raipur	Raipur-Dhamatari Road, mile 9th	3	51.88	57.12	63.78	63.87	62.29	43.4	21.3	48.0
		18	Satna	Rewa-Nowgong Road, mile 34	4	60.93	65.24	72.46	84.61	84.03	39.0	10.9	23.2
	Uttar Pradesh	19	Lucknow	Lucknow-Sultanpur Road, mile 4	45	21.65	25.11	22.74	24.77	25.58	31.5	11.5	32.0
	West Bengal	20	Burdwan	G. T. Road, mile 58	5	81.04	88.25	87.12	92.81	93.25	57.3	30.6	4.3
		21	Calcutta	Diamond Harbour Road, mile 9	1	97.15	101.90	102.0	100.7	95.67	55.2	27.9	3.8
	Assam	22	Gauhati	Gauhati Goalpara Road, mile 12	20	83.0	90.0	95.6	95.1	95.1	38.6	20.9	8.3
		23	Agartala	Agartala Assam Road, mile 2	5	--	78.49	80.75	83.82	--	39.7	19.2	30.0
	Bihar	24	Gaya	Gaya-Kawadah Road, mile 3	8	60.87	72.45	75.66	67.43	69.52	28.9	13.3	14.8
	Orissa	25	Cuttack	National Highway No. 5, mile 755	12	47.44	48.31	46.34	47.87	53.96	21.9	7.0	60.0
		26	Cuttack	National Highway No. 42, mile 13	4	83.95	85.10	83.76	77.76	81.38	29.9	10.9	34.9
	Madras	27	Madras	Mt. Paonamalli		60.15	64.45	75.56	76.88	83.87	29.4	13.8	46.5

		28	Vellore	Ranipet Krishna-giri Road, mile 4	15	25.86	34.65	36.49	33.76	36.01	--	--	--
	Andhra	29	Hyderabad	Hyderabad Bhongir Hanam Kunda Road, mile 2	8	50.55	61.16	61.50	70.48	77.71	34.4	18.2	46.8
	Mysore	30	Kolar	Cudappa Rly. Feeder, mile 1	15	39.38	41.94	58.42	51.02	51.52	30.6	14.2	51.0
	Gujarat and Maharashtra	31	Ahmedabad	National Highway No. 8, Karjan Makarpura sec. mile 8	30	16.18	18.26	19.94	22.58	22.58	23.6	9.4	52.0
		32	Baroda	Baroda Karjan Makarpura Road, mile 27	28	90.31	95.33	92.29	89.30	92.27	40.2	18.7	10.2
		33	Bhavnagar	New Jetty Road, mile 1	8	90.20	80.42	75.96	78.00	85.80	69.7	38.8	17.8
		34	Bhuj	Bhuj Anjar Road, mile 3	60	23.04	24.73	21.18	20.99	22.65	31.8	16.3	28.0
		35	Bombay	Bombay Agra Road, mile 20	5	66.50	67.50	80.64	82.42	83.47	46.9	19.3	36.5
		36	Jalagaon	Surat Dhulin Ealabad Nagpur Road, mile 195	20	--	79.12	86.15	88.09	--	73.9	36.3	9.0
		37	Junagarh	Junagarh Veravel Road, mile 2	30	67.03	70.61	73.01	84.32	87.54	50.1	25.2	22.2
		38	Junagarh	Junagarh Rajkot Road, mile 2	30	75.28	75.28	79.19	78.78	75.20	43.2	21.3	24.0
	Gujarat and Maharashtra	39	Nagpur	Nagpur-Raipur Road (N.H. 6), mile 5	--	91.33	82.85	82.25	87.20	92.51	66.3	32.8	6.2
		40	Rajkot	Rajkot Surendra Nagar Road, mile 5	10	84.44	88.05	86.80	84.48	88.77	69.7	30.0	10.5
		41	Surat	Surat-Dhulia Road, mile 8	28	85.31	91.08	92.85	93.75	97.30	53.0	24.6	17.0
		42	Bhandara	N. H. No. 6, mile 33	4	97.51	93.43	82.30	86.29	87.27	28.0	15.4	44.0
Airfield runway	Punjab	1		Amritshar[a]	3	92.7	92.7	91.3	98.0	98.9	26.6	10.3	6.0
	Rajasthan	2		Jaipur[a]	60	24.3	27.2	25.1	27.2	22.6	23.5	7.0	69.0
	Uttar Pradesh	3		Lucknow[b]	8	98.0	100.0	100.0	100.0	100.0	32.0	14.5	2.0
	West Bengal	4		Dum Dum (Calcutta)[b]	5	94.0	90.1	96.0	98.33	97.94	63.8	33.5	1.0
		5		Cooch-Behar[c]	10	71.0	74.0	73.7	71.0	68.7	47.5	23.5	10.0
	Assam	6		Agartala[b]	4	83.7	89.7	89.6	92.1	91.7	39.4	15.7	28.1
		7		Gauhati[b]	2	--	75.5	77.5	80.2	--	30.9	14.2	22.0
		8		North Lakhimpur[d]	--	--	--	--	--	--	23.2	6.2	43.2
	Orissa	9		Bhubneshwar[b] (Cuttack)		83.32	77.18	75.82	79.23	76.50	32.7	14.1	34.0
		10		Gaya[b]	1	83.6	91.0	90.5	97.0	94.3	46.3	27.4	5.7
	Madras	11		Madras[b]	6	72.4	75.2	72.3	83.5	83.0	23.5	7.4	63.0
		12		Tiruchirapalli[b]		80.5	84.7	88.4	90.2	87.4	43.2	23.9	44.8
	Andhra	13		Begumpet[b]	8	45.4	43.1	56.2	55.0	56.7	34.6	14.8	46.0
		14		Santacruz[b] (Bombay)	4	98.9	94.7	93.5	95.2	91.5	75.0	39.5	5.4
		15		Ahmedabad[b]	20	51.07	56.35	59.87	51.50	50.98	22.4	6.2	64.7
		16		Nagpur[b]	3.5	92.6	91.4	92.0	88.1	90.7	--	--	--
		17		Bhavnagar[b]	3	97.6	96.3	99.8	100.0	100.0	47.9	21.8	23.0
		18		Bhuj[b]	19	36.9	38.2	32.5	28.17	32.12	20.3	5.0	70.0
		19		Rajkot[a]	--	42.4	44.5	40.82	46.0	42.3	34.0	9.9	44.0
	Delhi	20		Safdarjung[a]	8		64.2	64.3	72.8		31.9	14.4	18.3

[a] Flexible pavement with bituminous surface.
[b] Cement concrete rigid pavement uncovered, except airfield sites 4, 7, 11, and 16 which are covered with asphaltic concrete.
[c] Gravel surface.
[d] Natural landing ground.

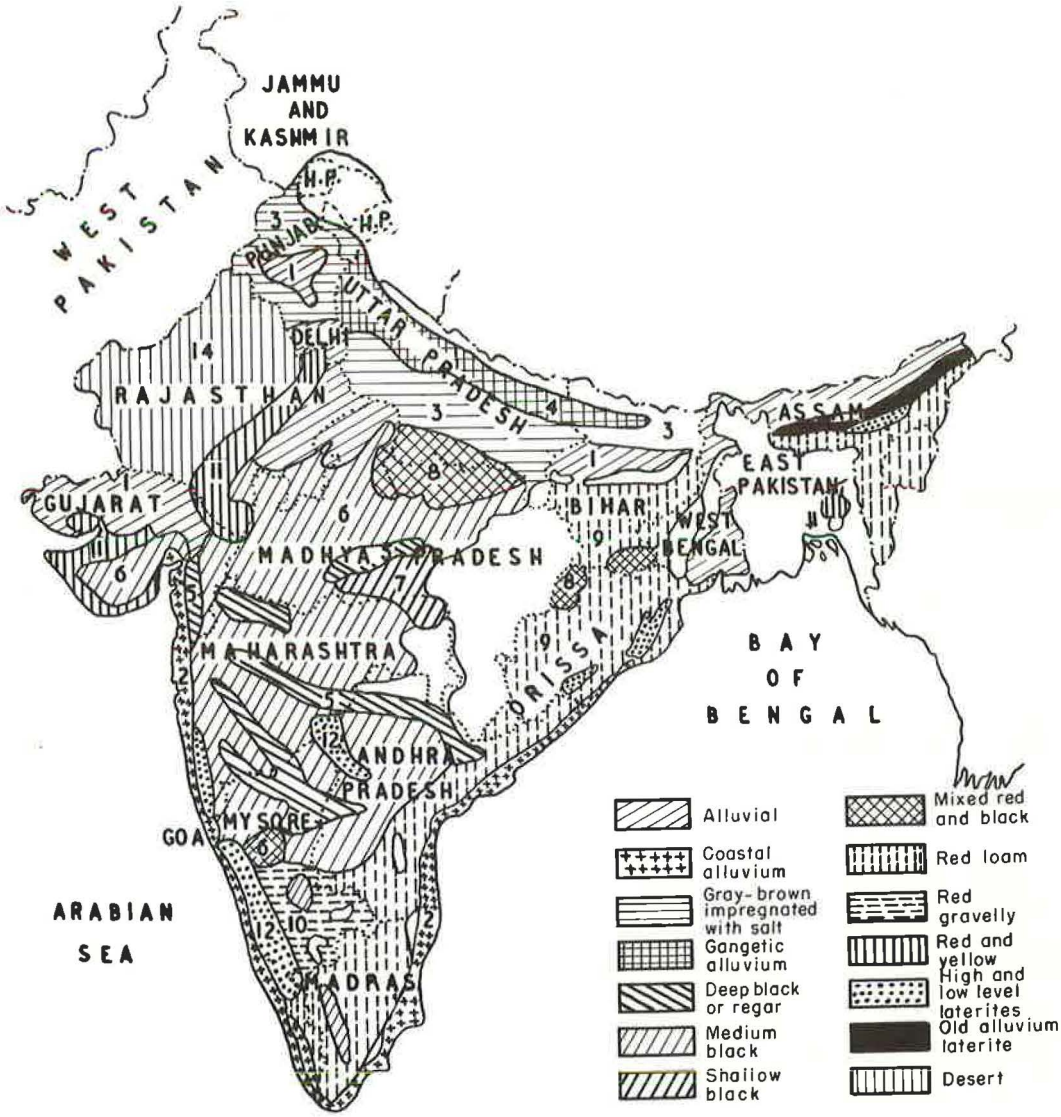


Figure 2. Soil map of India.

For want of facilities all the airfields could not be investigated and, therefore, only 20 runways, which are fairly well spread throughout the country, were selected for investigation. The location of these runways is shown in Figure 3, and also in the Appendix. Out of 20 airfields selected for the study, 13 had rigid cement concrete pavement, 5 flexible pavement, and the remaining 2 had a natural landing ground (Table 1).

Sampling Period

It has been discussed previously that wetting of the subgrade at a particular site having proper side drainage, depends on the intensity of rainfall. With the onset of the monsoon, the water table starts moving up, thereby increasing the moisture content of the subgrade. The worst condition of subgrade moisture will, therefore, be reached at the time of the withdrawal of monsoon, when the site has had maximum rainfall and consequently the highest water table. This fact was confirmed by taking

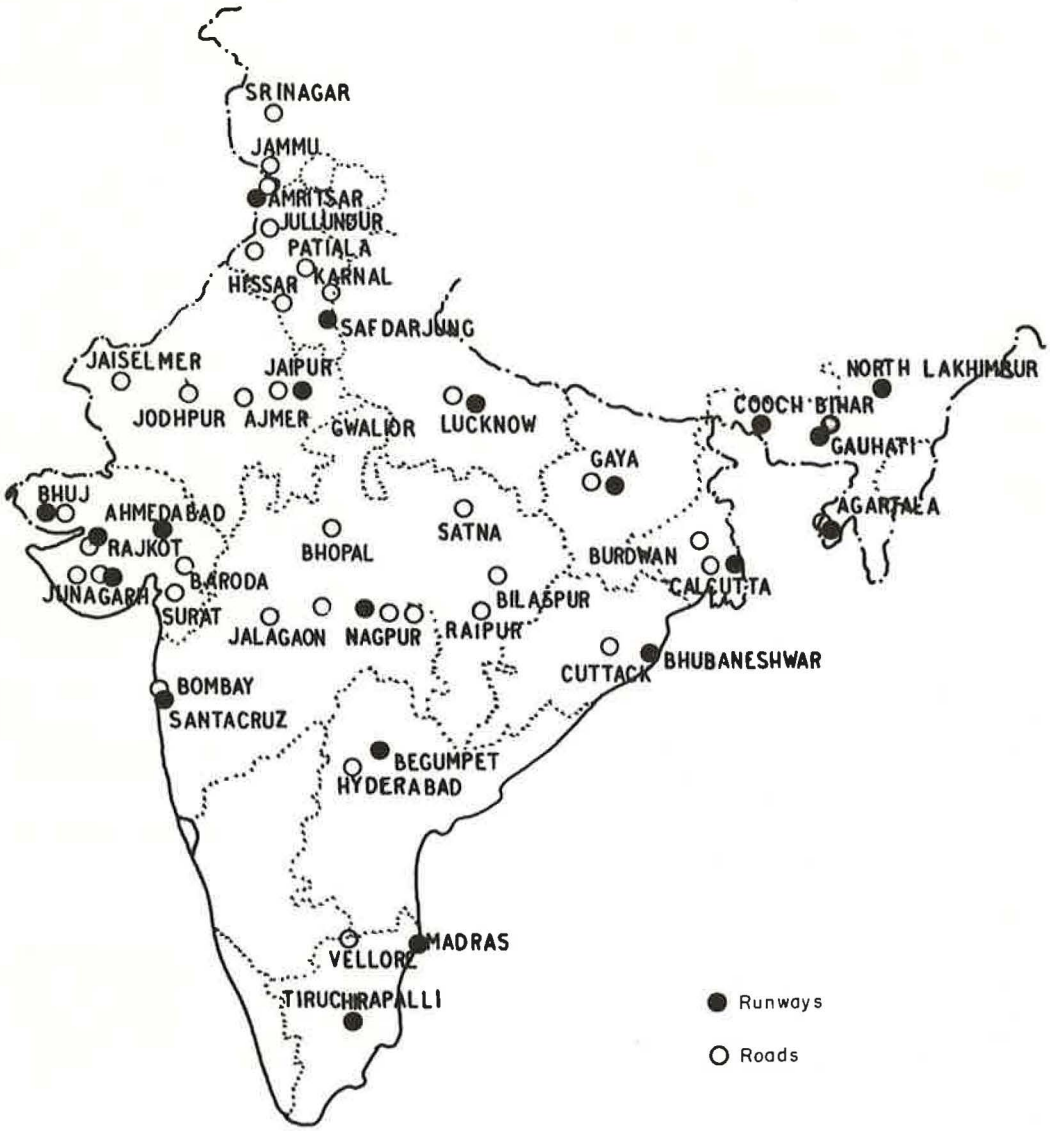


Figure 3. Sampling sites for roads and runways.

observations all year at three different stations in alluvial plains having different intensities of rainfall. The results of subgrade moisture during different months of the year are given in Table 2. It appears that the highest moisture content of the subgrade is attained between September and October for these particular stations, which coincides with the recession of the monsoon.

It was, therefore, decided to take samples of the subgrade in different parts of the country at the time of withdrawal of the monsoon. Because the dates of withdrawal of the monsoon in different areas are likely to change by a few days from year to year, arrangements were made with the Meteorological Department for telegraphic intimation about the probably date of withdrawal of the monsoon for that year, so that the samples of the subgrade could be taken at the most appropriate time. Information gathered from the Irrigation Department showed that the water table does not start

TABLE 2

SEASONAL SUBGRADE MOISTURE VARIATION UNDER ROAD PAVEMENT

Month	Subgrade Moisture (%)		
	Lucknow	Delhi	Mathura
Jan.	2.9	14.1	19.3
Feb.	4.8	15.2	--
March	4.5	16.3	18.6
April	--	6.8	--
May	--	8.0	19.1
June	3.1	6.5	15.9
July	2.1	17.7	--
Aug.	--	20.4	19.1
Sept.	--	22.3	26.0
Oct.	7.6	17.1	--
Nov.	--	18.6	18.8
Dec.	3.5	17.1	--

receding immediately with the withdrawal of the monsoon, but that it takes a few days to recede. This gave some flexibility to the duration of sampling at different sites without seriously affecting the highest moisture content of the subgrade.

Location and Frequency of Sampling

It has been stated earlier that wetting of the subgrade can take place either from the water table when it is high enough, or from the wet berms to a width of about 3 ft, towards the center of the road, when the water table is low. In any case, if the sampling point is fixed at 3 ft from the edge towards the center of the road, it will take care of both processes of wetting the subgrade. Based on these assumptions, the sampling points were fixed at a distance of 3 ft from the edges towards the center of the road. It was also advantageous because, incidentally, this place is normally subjected to the maximum traffic effect, being under the wheel track in most of the roads.

In the case of runways, fixing the sampling point at a distance of 3 ft from the edges was of no practical use, as this part of the runway is never under traffic. The sampling points were, therefore, fixed at a distance of 10 to 15 ft from the edges towards the center of the runway to get as close to the subgrade condition of the track as possible without interfering with the air traffic.

To get a good average, five samples in a mile every 1,000 ft apart were taken for both the roads and the runways.

Depth of Sampling

The depth to which stresses due to traffic will travel down to the subgrade will depend on the area of contact and the type of pavement. For the same intensity of traffic, the stresses will travel to a greater depth in the case of a flexible pavement as compared to a rigid pavement, but even in the case of a flexible pavement, the stresses are not likely to travel even under heavy traffic beyond a 3-ft depth of the subgrade. Undisturbed samples of the subgrade were, therefore, taken to a depth of only 3 ft, by driving thin steel tubes with an area ratio of about 20 percent.

Vegetation in the Vicinity

The type of vegetation growing close to the road was also recorded to see if this had any marked effect on the subgrade moisture. It was, however, observed that there was no difference in the moisture content of the subgrade due to the difference in the nature of vegetation growing at that time of the year. This can probably be attributed to the fact that vegetation had plenty of water from rain itself and, therefore, the moisture content of the subgrade was not affected. It is more likely that vegetation will have an influence on the subgrade moisture during the dry season.

Testing and Samples

The undisturbed soil samples collected to a depth of 3 ft from the various stations were subjected to the following tests in the laboratory:

1. Moisture content.
2. Dry bulk density.

3. Specific gravity.
4. Liquid limit.
5. Plastic limit.
6. Sand content (fraction coarser than 200, U.S. std. sieve in soil mortar).

Laboratory Testing Procedure

It has been stated earlier that undisturbed samples of the subgrade for a depth of 3 ft were collected in a sampling tube. For laboratory tests, samples from various depths of the profile were obtained by pushing out the samples by means of a plunger. In the case of very clayey soils, this procedure did not work well and undisturbed samples from the tube were taken by inserting another tube of a smaller diameter, with a sharp cutting end. The type of tests and their frequency of determination in the 3-ft profile is discussed next.

Moisture Determination.—The moisture content of the subgrade profile was determined in the top 2 in. in the middle of first, second, and third foot; and also in the last 2 in. of the third foot. The moisture in the top 2-in. sample was determined to find out if there was any accumulation of moisture at the top immediately under the payment.

Dry Bulk Density.—The dry bulk density for each foot of the sample was determined. Because a large number of samples were to be dealt with, the method of determining dry bulk density was expedited by pushing a thin-walled cylindrical mould with a 2-in. diameter and a height of about 0.5 in., into the undisturbed soil sample. Because the mould had a known weight and volume, the test resolved itself to the determination of weight of the mould with the sample, before and after drying in the oven. The dry bulk density generally varied from 1.6 to 1.7 g per cc, but no results are recorded in this paper.

Specific Gravity.—The specific gravity of each foot of soil profile was determined by means of a specific gravity bottle according to the standard method, and the values generally ranged between 2.65 and 2.75 g per cc.

Consistency Limits.—An average sample of 1-ft soil profile was tested for liquid limit, plastic limit, and fraction coarser than 200 U.S. standard sieve in the soil mortar. The results are given in Table 1.

Degree of Saturation.—The moisture present in the soil is expressed as the percentage moisture in the dry weight of soil. This is not very informative as the stability of a soil is dependent not only on the moisture but also on the final moisture-holding capacity under a saturated condition for a particular dry bulk density in the field. The moisture content is, therefore, expressed in this paper as the degree of saturation, which also takes into consideration the dry bulk density and specific gravity of soil. The degree of saturation was calculated according to the following formula:

$$\text{Moisture content to fill voids completely} = \frac{\text{Specific gravity} - \text{Dry bulk density}}{\text{Specific gravity} \times \text{Dry bulk density}} \times 100$$

$$\text{Degree of saturation} = \frac{\text{Moisture content}}{\text{Moisture content to fill voids completely}} \times 100$$

ANALYSIS

From the data of moisture content, dry bulk density, and specific gravity of the subgrade soil samples, the degree of saturation of the subgrade for the top and bottom 2-in. samples as well as the average of the first, second, and third foot depths of the subgrade was calculated. The results for the degree of saturation which is an average of five samples at a particular site are given in Table 1.

The results show that by and large there is a regular moisture gradient in the subgrade—the moisture content increasing with the depth. This is true both for roads and runways irrespective of the soil type and rainfall conditions. There are, however, some exceptions. In the case of heavy clays (such as black cotton soils, which are

montmorillonitic in nature), the moisture content in the top 2 in. of the subgrade immediately under the pavement is the highest. This is shown in Table 1 by road sites 33 and 39 and airfield runway site 14 with the liquid limit between 66 and 75 percent and the plasticity index between 33 and 40. This observation is, however, not fully supported by road site 40 soil, which is almost as clayey as the other soils.

It is quite likely that due to a poor sealing surface, some moisture might have traveled down to increase the moisture content in the top 2 in. of the subgrade. More data are, however, required to establish this phenomenon. Also, in the case of road sites 6, 9, 30, 32, and 34 which vary in texture from loamy to silty clay loam and lie in dry areas with a low water table, the moisture content in the first foot of the subgrade is generally higher as compared to moisture in the top 2 in. or a foot or two below it. In the absence of sufficient data, it may not be possible to offer a proper explanation, but it has been observed in certain dry areas in India that there is a tendency for the moisture to travel in the vapor phase on account of the thermal gradient in the subgrade which causes the accumulation of moisture at a certain depth towards the surface.

The observations made earlier during the discussion of the data on moisture gradient are equally true for airfields except that, inasmuch as there is no embankment, the surface is nearer the water table as compared to roads in the same zone, thereby resulting in a comparatively higher degree of saturation.

Because there are not many cement concrete road pavements, it is not possible to compare the degree of saturation under a cement concrete and water-bound macadam with sealed surface. It is, however, possible to some extent in one of the cases where a bituminous-sealed water-bound macadam and an airfield with an almost identical thickness of crust having a water-bound macadam base and having six in. of cement concrete (1:2:4) as the wearing course lie in a particular zone with the same water table. This refers to road site 29 and airfield site 13 in Table 1. It appears from the results that the degree of saturation under a bituminous-sealed surface is higher than under a cement concrete pavement. This is only an isolated case and requires a separate study to establish it fully.

Table 1 also shows that in a large majority of cases the variation in the degree of saturation within a 3-ft depth of the subgrade ranges generally between 5 and 10 percent. The degree of saturation for different parts of India as given in this paper is shown in Figure 4 to be about 10 percent.

The degree of saturation of the subgrade in dry areas abounding in predominantly sandy soils such as those met in the southwest of Punjab and Rajasthan is of the order of 20 to 40 percent. The western parts of Rajasthan being drier than the eastern parts, the different being due to the difference in the intensities of rainfall.

The alluvial soils with a rainfall of about 30 in. (such as those met with north of Gujarat State and south of Delhi) have degree of saturation ranging between 60 and 70 percent. As the rainfall increases in the same zone to about 50 in. per annum as in case of the Indo-Gangetic plains, the degree of saturation also increases to between 80 and 90 percent. With the further increase in rainfall to about 75 in. per annum and above, the degree of saturation further rises to between 90 and 100 percent. These conditions of high rainfall are encountered in the eastern part of West Bengal and north of Assam.

The red and yellow soils (such as those encountered in Central India) with rainfall ranging between 50 and 75 in., have a degree of saturation of about 70 percent. For the same rainfall intensities, the red loam soils have a slightly higher degree of saturation (80 percent). This is due to the fact that red soils contain a higher percentage of clay as compared with yellow soils.

The black cotton soils which cover almost the whole of Central India have a rainfall of 20 to 75 in. per year. The degree of saturation irrespective of rainfall intensity is 90 to 100 percent.

The coastal alluvium with rainfall above 100 in. has a degree of saturation of about 100 percent.

CONCLUSIONS

The study indicates that the degree of saturation of the subgrade consisting of a particular type of soil follows more or less the same pattern as the rainfall contours. There are, however, some small deviations due to abrupt changes in the texture of the soil. The only exception to this being the area abounding in black cotton soil, where the degree of saturation ranges between 90 and 100 percent irrespective of the intensity of the rainfall. This is due to the fact that black cotton soils have high colloidal content which exerts great suction to pull up moisture from the water table at various depths.

The study also shows that the phenomenon of "equilibrium moisture content," as found in some parts of England under sealed surface, is not observed in India.

It can be inferred that for the prevailing rainfall intensities (or water table conditions) in India, the design of the road pavement need not be carried out at complete saturation for all the places in India, as practiced now according to standard procedure.

Because the degree of saturation in different parts of the country for a particular depth of the water table is known from this study, subsequent small changes in the degree of saturation from year to year can roughly judged from the corresponding rise or fall of the water table, or more precisely, from laboratory study. This is, however, true only when the water table is within a certain range of the capillary fringe. When the water table is beyond a certain depth (as in the case of dry areas), then the present information regarding the degree of saturation can hold good for all practical purposes for some time to come, as there is not much likelihood of abrupt increase in rainfall intensity, the nature of the soil remaining the same.

It is admitted that a study of this type cannot be very precise to start with, but it does make out a case for future work, for more exact demarcation of boundaries for each zone, and also for taking up laboratory studies of a fundamental nature on subgrade moisture movement.

PRACTICAL ASPECTS

The present study has shown that the degree of saturation of the subgrade in different parts of the country during the worst part of the year varies from 20 to 100 percent. It is, therefore, logical that the design of a flexible road or runway pavement should be carried out at the moisture content equivalent to the highest degree of saturation actually attained in the field, and not at saturation, as is done at present according to the standard CBR test procedure.

This will, therefore, require a modification in the existing procedure of determining CBR, so that the test, instead of being carried out under a saturated condition, can be conducted at a moisture content corresponding to the degree of saturation prevailing in the field. One of the practical methods to achieve this would be to compact the soil to a desired density at a moisture content corresponding to a particular degree of saturation. This will require varying intensities of compacting effort, which will increase with the decrease in moisture content. The samples thus compacted could immediately be subjected to the CBR test. A study carried out at the Road Research Laboratory, London (2), with a number of soils statically compacted according to the procedure previously mentioned, shows that the CBR determined at varying degrees of saturation bears a straightline relationship when drawn on a semilog basis. It should, therefore, be possible to calculate the CBR at various degrees of saturation from a single test value determined experimentally.

It is known however, that strength of soil is governed not only by the moisture content and dry bulk density but also by the manner in which the particles are arranged. The preceding technique has, therefore, a drawback inasmuch as the method of compaction (especially at low moisture) is very drastic and does not simulate the field condition. The results thus obtained in the laboratory are, therefore, not likely to be of much practical value.

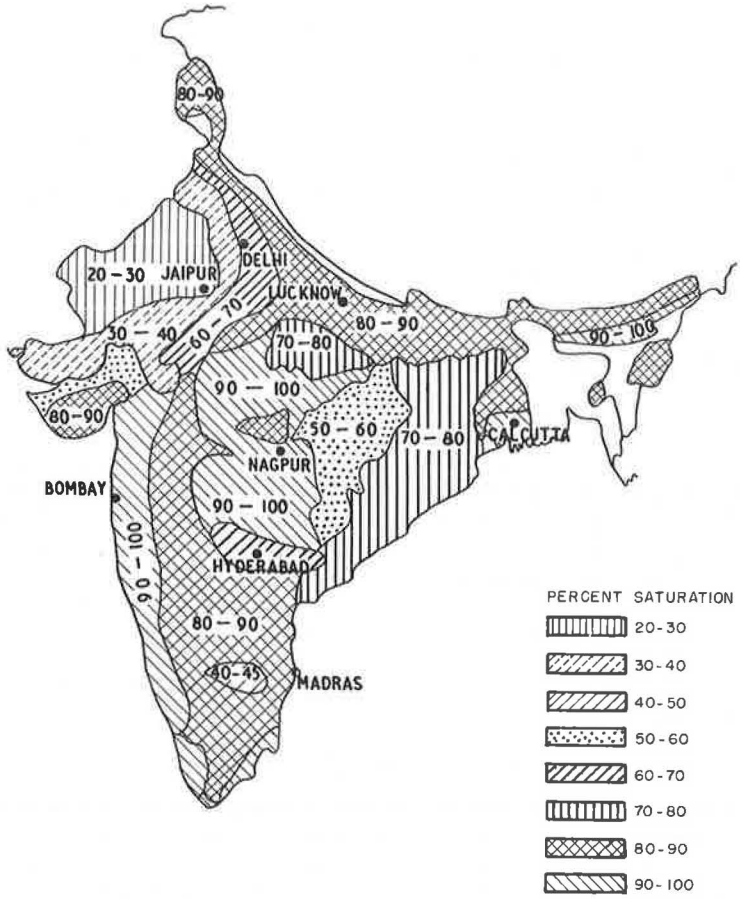


Figure 4. Map of degree of saturation of subgrade in India.

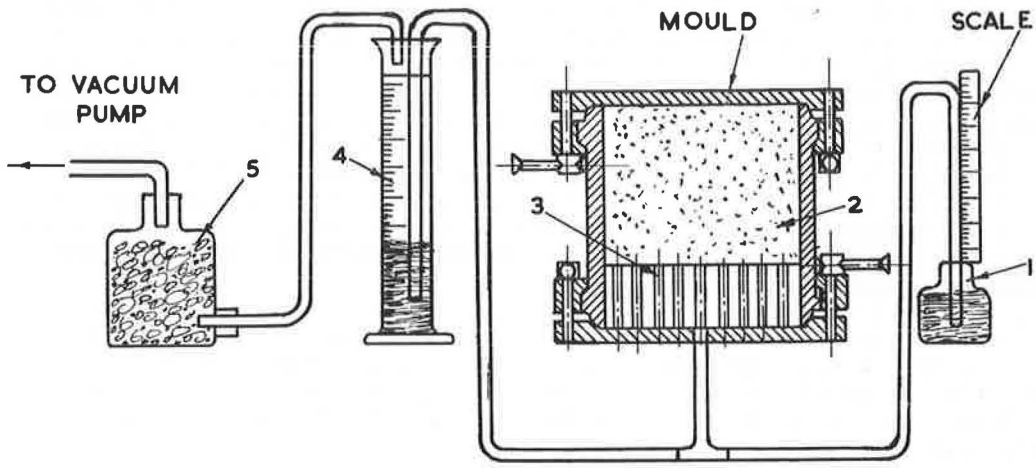


Figure 5. Laboratory set-up for bringing compacted soil to varying degrees of saturation: (1) manometer, (2) soil sample, (3) perforated wooden block, (4) graduated cylinder, (5) calcium chloride.

PROPOSED METHOD FOR ADJUSTING DEGREE OF SATURATION THROUGH SUCTION

The variation in the moisture content of the subgrade in actual practice is brought about by the movement of the water table. As the water table falls, it exerts negative pressure resulting in the decrease of moisture content in the subgrade and vice versa. In this technique, the degree of saturation existing in the field is simulated in the laboratory without disturbing the structure of the soils.

The soil is compacted dynamically at optimum moisture to a desired density. It is then allowed to saturate for four days according to standard procedure. The mould is then taken out and the 2-in. thick metallic spacer is replaced by a wooden perforated spacer of exactly the same size, to permit easy flow of water. A metallic base with a central hole is then screwed to the mould and carefully waxed to make it airtight. A plate is fixed, at the other end of the mould where the compacted soil crust is up to the top, and properly waxed. The base of the mould is then connected to the vacuum pump through a measuring cylinder. The set-up is shown in Figure 5. The vacuum is then applied; from the water removed from the specimen and collected in the cylinder, an approximate idea of the degree of saturation of the soil sample in the mould is obtained. A number of tests can be run with different moulds and brought to varying degrees of saturation for determining the CBR. Some preliminary trials with sandy soils have shown that a vacuum has to be created for about 12 hours to bring the degree of saturation down from 100 to 50 percent. The time for other degrees of saturation is given in Table 3.

TABLE 3

TIME FOR SOME DEGREES OF SATURATION

Deg. of Sat.	Period of Evac. (hr)
90	0.25
80	0.75
70	3.0
60	6.0
50	12

There will, however, be some moisture gradient in the compacted crust, which will increase as the degree of saturation falls. In such cases it will be better to base the CBR on the degree of saturation corresponding to the moisture content determined from the center of the mould.

Some initial trials have shown that the relationship is linear between the CBR and the degree of saturation ranging between 90 and 50 percent. There is, however, a tendency for the CBR at 100 percent saturation to shift from the line.

ACKNOWLEDGMENTS

The work described in this paper was carried out as part of the program of the Central Road Research Institute, New Delhi, India. The paper is presented by permission of the Director Central Road Research Institute. The author wishes to thank Shri H. R. Aggarwal for assisting in the laboratory work, and other members of the staff of the Institute, for field sampling.

REFERENCES

1. "Investigation to Study Moisture Conditions Under Roads in Kenya." Road Res. Lab., Res. Note RN/3807/MPOR. FHPW, Harmondsworth (July 1960).
2. Davis, E. H., "The California Bearing Ratio Method for the Design of Flexible Roads and Runways." Geotechniques (June 1948).

DIVISION OF INDIA INTO DIFFERENT ZONES ON BASES OF RAINFALL AND SOIL TYPE

Annual Rainfall (in.)	Alluvial Soil	Coastal Alluvium	Alluvial Soil with Salt	Gangetic Alluvium Calcareous	Black Cotton Soil			Mixed Red & Black Soils	Red Loam	Red Gravelly Soil	Red & Yellow Soils	Laterite & Low & High Soils	Laterite Old Alluvium	Desert Soils
					Deep Black	Medium Black	Shallow Black							
<10														Jaisalmer
10-20	Bhatinda	Vellore	Hissar	Jodhpur							Bhuj[1]			
20-30	Shrinagar, Delhi[1]	Bhavnagar[1]	Karnal		Jalgaon	Kurnool, Ahmedabad[1], Junagadh, Hyderabad[1]			Trichinopoly[1]	Mandya, Banga-lore, Kolar	Rajkot Jaipur[1]			Ajmer
30-50	Jammu, Gwalior, Patiala, Gaya[1]	Surat	Amritsar[1] Jullundur, Lucknow[1]		Baroda	Nagpur[1]	Betrul	Satna	Purlia		Bilaspur			
50-75	Calcutta[1]		Bombay[1], Madras[1]			Saugor	Bhandara			Ranchi	Raipur	Cuttack[1]	Burdwan	
75-100	North Lakhimpur[1]								Manipur Rd					
100-150	Agartala[1], Gauhati[1], Cooch[1], Bihar[1]													
150-200													Shillong	

[1]Runways.

Another paper, sponsored by the Committee on Surveying, Mapping and Classification of Soils, was presented at the 42nd Annual Meeting by A. H. Stallard and Glenn Anschutz. This paper, "Use of the Kelsh Plotter in Geo-Engineering and Allied Investigations in Kansas," includes discussion of the use of airphotos in geological, slide area, hydraulic and hydrographic investigations and in bridge deck and road condition surveys. Consequently the paper will be published in another issue of the Research Record devoted to Photogrammetry and Aerial Surveys.