*SUBSURFACE INVESTIGATION
FOR
INDIANA HIGHWAYS*

*SEPT. 1965
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*Joint
Highway
Research
Project*

by
D. P. McKITTRICK

*PURDUE UNIVERSITY
LAFAYETTE INDIANA*

SUBSURFACE INVESTIGATION FOR INDIANA HIGHWAYS

To: G. A. Leonards, Director
Joint Highway Research Project

September 24, 1965

From: H. L. Michael, Associate Director
Joint Highway Research Project

File No: 1-3-4
Project No: C-36-29D

Attached is a Final Report entitled "Subsurface Investigation for Indiana Highways". It has been prepared by Mr. David P. McKittrick, Graduate Assistant on our staff, under the direction of Professor C. W. Lovell, Jr. Professor R. D. Miles also provided guidance and assistance during the research. Mr. McKittrick also used the report for his MSCE thesis.

The report examines the problem of programming subsurface investigations for highway design and construction by a case study approach. The results showed that the usefulness of the tools of geologic, pedologic and airphoto coverage of a site provided optimal results where each was available and wisely used. The study indicated for each case study made that a subsurface investigation program based on the office use of geologic, pedologic and airphoto coverage resulted in an economic saving.

The report completes the research proposed by Mr. McKittrick and approved by the Board on March 6, 1964. The report is submitted for acceptance.

Respectfully submitted,

Harold L. Michael, Secretary

HLM:bc

Attachment

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Final Report

SUBSURFACE INVESTIGATION FOR INDIANA HIGHWAYS

by

**David P. McKittrick
Graduate Assistant**

Joint Highway Research Project

File No: 1-3-4

Project No: C-36-29D

Purdue University

Lafayette, Indiana

September 24, 1965

SUBSURFACE INVESTIGATION FOR INDIANA HIGHWAYS

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ABSTRACT

McKittrick, David Paul, MSCE, Purdue University, January, 1966.

Subsurface Investigation for Indiana Highways. Major Professor:

Dr. C. W. Lovell, Jr.

This thesis examines the problem of programming subsurface investigations for highway design and construction from a case study approach. Four design sections of the Indiana Interstate Highway System were selected for intensive study. The areas selected are representative of the physiographic unit in which they are located. Information from geologic and pedologic sources, as well as airphoto coverage was studied, and results of this study were used in planning the exploration program. "Results" of the proposed investigation were compared with results of soil surveys conducted previously for the design sections.

It was shown that the usefulness of the "tools" of geologic, pedologic and airphoto coverage varied individually and collectively with the location, but that optimal results were obtained where each was available and was allowed to make its own somewhat unique contribution. The cost of subsurface investigation (for interstate highways in Indiana) was found to be dependent upon such factors as the geologic origin and complexity of parent materials, the topography, and the general soil textures. However, in each of the case studies an investigation program planned from the kind of office study described above could be

implemented at a lesser cost than the program which did not include said study phase. It is believed that the economic saving was accomplished without any loss in detail of engineering characterization of the subsurface.

INTRODUCTION

The term "subsurface investigation" is a broad and comprehensive designation used with reference to all engineering activity which serves to define and describe those subsurface materials which may enter the design and construction functions. It includes soil explorations and surveys, sampling, and evaluation of properties and characteristics by test.

In general, subsurface investigations may be classified as preliminary, reconnaissance, or detailed. Data obtained from preliminary and reconnaissance surveys are of influence in the selection of a route (or routes) that will satisfy the over-all transportation requirement. These investigations may involve little more than a regional evaluation of soil conditions, with minimal physical field exploration. When the final location of the route has been selected, a detailed subsurface investigation is conducted to provide sufficient information for adequate design and construction control.

Specifically, the detailed survey furnishes data which are needed to:

1. establish the final location of the grade line,
2. design or proportion cut slopes and establish the disposition of cut material,
3. establish the sources of borrow for subgrades and embankments, set the type of treatment required for subgrades, and design or proportion the embankments,

4. determine the foundation conditions for structures including embankments,
5. delineate those materials which are unsatisfactory for any engineering usage.

In planning and implementing a subsurface investigation for a proposed engineering facility, several approaches may be adopted. At one extreme, the investigation may be specifically designed for the proposed facility in its particular physical environment. Since each facility-environmental situation is unique, such an approach is ideal from an academic standpoint. At the other extreme is the investigational procedure which is designed for a class of facilities in a variety of environments, i.e. the "standardized" program. That these approaches are indeed extremes is demonstrated in the following discussion.

The fully designed or "ideal" program proceeds in steps from a general evaluation of subsurface conditions to a specific definition of the thicknesses and the physical (and sometimes chemical) characteristics of the profile constituents. The degree of definition and manner of characterization is governed by a collective consideration of the following factors with regard to the proposed facility:

1. the type (highway, airfield, dam, etc.),
2. the size and cost,
3. the service life,
4. the design criteria,
5. the nature of the subsurface (homogeneity, soil types and textures, ground water levels, etc.).

Of considerable aid in the general evaluation of the subsurface conditions is the significant information available to the soils engineer from the related fields of geology, pedology and aerial photography. From a study of this information, major soil groups can be generally delineated. Actual physical operations can then be concentrated near the major soil boundaries, in or near "trouble spots" (suspected to be occupied by weak or compressible soils), and in and around areas where major cuts, high fills, or any heavy foundation loading is likely. Fewer explorations are conducted in areas of subsurface uniformity, or where materials are inherently good, or in areas of relatively minor engineering activity. In all of these explorations, the best practicable techniques are applied in examining the profile, extracting and testing soil samples, and in evaluating the physical characteristics of materials. In the "ideal" program, there is engineering logic for, and economic justification of all operations. The investigation furnishes sufficient information to design the proposed facility with an adequate factor of safety, no more, no less.

The "standardized" subsurface investigation, because it must hold for many projects in many different geographic locations, cannot properly take into account the distinctive characteristics of any given facility-environment situation. For this reason, such details as boring type, location, spacing, and depth are governed largely by the geometrics of the proposed facility, with little regard to regional peculiarities. Such an approach provides minimum incentive for studying available information from related sources, since this

information is not permitted to influence significantly the exploration program. Such a program excludes or discourages the use of modern and/or specialized techniques and tools, since these are either not completely verified by experience or are not applicable to every project. The amount of information furnished by arbitrary spacing and depth rules, and from tests on a specified number of samples is often significantly in excess of that utilized in the design of the proposed facility. In other instances an overly conservative design is necessary because detail is lacking in certain critical areas.

In most instances, it will be difficult to implement the "ideal" program because of lack of the necessary specialized talent and the economics of time and money. On the other hand, to employ a subsurface investigation which has not been based, at least in part, on the principles of the "ideal" program is questionable engineering practice. The alternative is to specify a subsurface investigation procedure which is a suitable compromise between the idealized and the standardized. This study investigates and develops such a compromise in part.

Purpose and Scope

The objective of setting forth guidelines for an "optimal" subsurface investigation becomes more practicable as limits are set on both the type of engineering facility involved and the geographic location for said facility. In this case, the Interstate Highway System within the State of Indiana is the facility for which procedures are to be optimized. Lest the reader conclude that the

present advanced state of development of this System limits the practical usefulness of the study, it is emphasized that the concepts presented are equally applicable to the many miles of highway of primary importance which will be built in the future.

There exist along any highway route, sites of major activity, i.e. major cuts and fills, grade separations and bridges. Such sites deserve detailed attention relative to subsurface investigations, which is not included in this study, but which is proposed as the subject for future supplementary studies. The emphasis here is upon the highway facility as it exists at grade or in minor cut or fill.

Specifically this study proposes to:

1. Review the extant practices of subsurface investigation for the Interstate Highway System, with particular regard to:
 - (a) the use of relevant information from the fields of geology, pedology, and airphoto interpretation,
 - (b) the use of spacing and depth rules for borings,
 - (c) stipulation as to number of soil samples required,
 - (d) the quantity and types of laboratory tests performed on samples.
2. Assess with regard to particular projects the value in planning subsurface investigations of information from the related fields of geology, pedology, and airphoto interpretation.
3. Compare the present unit costs of subsurface investigation in different physiographic units of Indiana with those of project designed investigations for the same areas.

4. Indicate possibilities for obtaining more valuable engineering information at about the same cost, or adequate engineering information for less cost, through revision of subsurface investigation practices.

Much has been written of a general or philosophical nature relative to the topic of this study. However, the objective here was to accomplish practical problem solving. For this reason, four sections of the proposed Interstate Highway System were selected as cases for intensive study. These cases were selected with the advice of the state soils engineer. They are representative of four major soil-rock and landform situations in Indiana. Literature, map and photographic studies were used to predict the soils and soil exploration problems in these areas. These evaluations were used in turn to plan a detailed "optimal" field investigation program for each section, which was specific with regard to boring, sampling, and testing operations.

Subsurface investigations previously performed under present practice guidelines were available in each of these four areas. Data from these explorations were used to assess the reliability of the "optimal" method in planning a subsurface program. Unit costs for the actual or completed surveys were available, and hence costs of the actual and proposed investigations could be compared.

The potential for gaining more information for the same cost, or of achieving adequate definition of the subsurface at a lesser cost by revision of procedure, varied from region to region. Explanation of these differences was possible, in part, and formed the basis of a regional approach to subsurface investigation.

GENERAL REVIEW OF SUBSURFACE INVESTIGATION PROCEDURES

Introduction

A complete review of the literature pertaining to subsurface investigations for highway location, design and construction would be beyond the scope of this study. However, a primary purpose of the study was to examine the related sciences of geology and pedology and the art of airphoto interpretation, and to determine specifically what information from these fields could contribute to the proper planning and interpretation of subsurface investigations. Accordingly, the review can be separated into distinct phases. The first phase encompasses a brief review of the related fields of geology, pedology, and airphoto interpretation. A second phase includes a review of various publications from these fields, to determine which publications offer the strongest assistance in planning and programming the actual explorations in Indiana.

It has been postulated that subsurface investigations can be progressed most intelligently when there is a sound understanding of the engineering problems involved in the design and construction of the specific proposed facility (58, Chp. 10).¹ Consequently, the

¹

Numbers in parenthesis refer to items in the Bibliography.

third phase encompasses a brief review of the engineering problems associated with highway location, design and construction.

The final phase of the review includes an examination of current subsurface investigation procedures. From information offered in this section, the writer establishes a basis for the investigational procedures employed in the case studies.

Geology

The science of geology is the foundation for the procedure of subsurface explorations. A proper understanding of the subject is therefore essential if explorations are to be progressed intelligently. However, the science is vast, and certain subdivisions of primary importance need to be isolated for our purposes. These subdivisions are, (1) physical geology, (2) physiography or the concept of physiographic regions, and (3) stratigraphy.

Physical geology deals with the nature and properties of the materials composing the earth, their distribution, and the processes by which they are formed, altered, transported and distorted, as well as the nature and development of the landscape.

Physiography is that branch of geology which deals with the systematic examination, description and classifications of landforms and their interpretation as records of geologic history (58, Chp. 10). Of major importance to the soil engineer is the concept of physiographic regions. Each region has its individual features, not only in regard to land relief but also in regard to the structure, type and origin of the bedrock and the sequence of geologic events responsible for the types and characteristics of soil material. The physiographic region

also forms a convenient unit for regionalizing soil survey procedures and costs, as will be shown later.

A knowledge of stratigraphy or the arrangement of strata in the earth's crust assists the soils engineer in determining the geologic history of an area, in constructing columnar sections, and thus in predicting what materials he may reasonably expect to encounter at depth.

Various types of maps and reports are available to the engineer to assist in understanding the physical geology and stratigraphy of an area. Those of particular importance in planning subsurface explorations are described briefly below.

1. Folios of the Geologic Atlas of the United States. These folios, published by the United States Geological Survey (USGS) between 1898 and 1945, contain topographic, areal geology, and other maps of a 7.5-minute quadrangle. Included in report form are detailed descriptions of the geologic formations mapped, as well as several graphic and columnar sections. Where available, these folios afford great assistance.

2. Geologic Quadrangle Maps of the United States.¹ Successor to the Folios of the Geologic Atlas, the Geologic Quadrangle Maps are of two types. Bedrock or areal geology maps indicate the boundaries of visible consolidated strata and their inferred distribution where the units are covered by soil. Because the character of residual soils

¹

Regional geologic maps (1° of latitude and longitude) are also being published by the individual state geologic surveys in cooperation with the USGS (6).

may be inferred from a knowledge of the type of rock from which they were derived, these maps are of particular importance in areas where the soil cover is not of the transported variety. Surficial geology maps differentiate the unconsolidated surface materials of an area according to their age, details of deposition (such as glacial till, alluvium, and loess) and in some cases their textures. This is accomplished where said unconsolidated materials are relatively deep over bedrock.

On geologic maps, rock units and large unconsolidated deposits are identified by name and geologic age. The smallest unit mapped is generally a formation, but smaller subdivisions such as members of beds may be delineated. The areal extent of formations and members is indicated on geologic maps by means of letter symbols, color, and symbolic patterns. As an example, the glacial formations of Indiana are shown in Figure 1.

3. Topographic Maps. The erosional features and landforms portrayed by the contours shown on topographic maps indicate to some degree the type of soil and subsurface geologic conditions of an area. These maps are of major importance in planning subsurface explorations when used in conjunction with aerial photographs.

Also available to the soils engineer are many special geologic reports¹ which discuss areas and formations mapped on the quadrangle sheets. Other reports discuss large sections of a state where geologic conditions are similar.

¹

See Appendix A.

FIGURE 1. GLACIAL FORMATIONS OF INDIANA

A bibliography of geologic information relevant to subsurface explorations in Indiana is appended.¹ Selection of reference material was based on accuracy, suitability to the subject, and availability. Most references can be purchased at nominal prices from state or federal agencies.

Pedology

Some elementary knowledge of the science of pedology is necessary if the engineer is to utilize a major culmination of this science, the agricultural soil survey, in planning and progressing subsurface explorations. The pedological system of soil classification recognizes that movement of water from the surface downward leaches inorganic colloids and soluble material from the upper portion of the soil. The depth of leaching action depends on the amount of water, the permeability of the soil, and the length of time involved. This action produces distinct layers or horizons of soil collectively called the soil profile. The science further recognizes that a relationship exists between topographic features or landforms and the characteristics of the soils. It is postulated that where the factors of topographic expression, age, climate, vegetative cover and parent material are similar, a similar soil profile will develop (50).

The agricultural soil survey identifies and maps soil types, series, and associations. A soil type is a subdivision of the soil series that is based upon the texture of the surface soil. The soil series is a group of soils developed from the same parent material, having similar soil horizons, and with essentially the same

¹

See Appendix A.

characteristics throughout the profile except for the texture of the surface horizon. A soil association is any group of soils, with or without common characteristics, geographically associated in an individual pattern. (See Figures 14, 15, and 16, pages 93 and 94.)

Included in the soil survey report are descriptive profiles for each soil type mapped. These profiles indicate the texture, degree of natural compaction, presence or absence of hardpan or rock, lithology of the parent material, and drainage characteristics of each horizon. These descriptions are, however, somewhat qualitative and more importantly, the textural classification employed does not coincide with common engineering textural classification systems. Correlations between the United States Department of Agriculture (USDA) textural classification system and various engineering classification systems (not purely textural) have been attempted (43), and these are helpful where such data are available.

The soil survey report also describes the topography, ground surface conditions, obstruction to ground water movement, natural vegetation, size of farms, land utilization and general geography of an area. In recent agricultural soil surveys, engineering characteristics of the major soil series mapped are listed. This recognition of utility of the mapping for engineering purposes is a very significant development.

With proper understanding of the pedological system and especially where correlation data are available, the agricultural soil survey maps and reports may be used by the soil engineer to great advantage in planning field explorations. Many states (Indiana (60), Michigan (65), New Jersey (26), etc.) have not only determined the engineering

classification for many major soil series, but also the engineering problems associated with these series. Where available, such reports are of great utility.

The common geographic mapping unit for the agricultural soil survey is the county, although agricultural soil maps are available for the Nation, for individual states, and in some instances individual farms. The reports vary in accuracy and availability, depending usually upon the date of publication (22). The agricultural soil survey publications for Indiana are listed in Appendix B.

Airphoto Interpretation

Another source of information available to the soils engineer to assist him in planning and progressing subsurface explorations is airphoto interpretation. The interpretation of earth materials and geologic features from aerial photographs is a relatively straightforward procedure, but one which requires considerable experience if optimal results are to be realized.

Aerial photographs accurately record the results of the natural processes responsible for the physical features (landforms) of the earth's surface. Most of these features have distinct patterns composed of definite diagnostic elements. These include elements of form such as topography, drainage, and erosional features, and elements of tone and textures as related to soil and vegetative cover or land use. Intensive field checks have been employed to establish the ground situations responsible for various combinations of diagnostic elements. It has been shown (12), (39), (60) that similar earth materials or geologic features are reflected by similar airphoto patterns, and

further that these patterns are repetitive. Thus, two soils which have developed from the same parent material under similar conditions of climate, topography, and time will exhibit the same airphoto pattern.

When all the diagnostic elements of an area have been studied and evaluated, the engineer can determine the nature and extent of the various soils in that area. While only surficial materials and general parent material types can be directly interpreted from aerial photography, with knowledgeable supplementary use of information from geologic and pedologic sources, this interpretation can generally be extended to include soil textures, and approximate depth of materials. Airphotos also offer the engineer an over-all view of the project area with particular regard to topography, drainage characteristics, land use, economic geography, and accessibility.

All of the United States has been photographed by various agencies, and in many cases this coverage is readily obtained. A United States Geological Survey index of the agencies holding the photographic coverage is available (53).

Also available are engineering soil maps and reports prepared by the use of aerial photographs (40). The reports often include descriptions of the geology and physiography of an area and profiles of the soils mapped. The status of these maps and reports in Indiana is given in Appendix C.

Engineering Problems

Before a subsurface exploration program for highway location, design and construction purposes can be intelligently pursued, the engineer must identify specific problems expected to be encountered,

especially those that may be influenced by the subsurface conditions. Basically these problems can be classified as those concerned with excavations and embankments (cut and fill sections), and the determination of the highway cross section.¹

With regard to excavations, the subsurface exploration program should supply sufficient information to answer the following questions:

1. Are the materials encountered in the proposed excavations suitable for the construction of stable embankments?
2. Are materials encountered in the proposed excavations suitable for incorporation into the highway cross section as subgrade or subbase courses?
3. What procedures will be required to remove the material from the proposed excavations?
4. What precautions, such as erosion control or benching, must be taken to insure the stability of the cut section?
5. What side slopes are required?

With regard to embankments:

1. What construction control procedures will be necessary to insure proper placement of material in fill sections?
2. Will the loads imposed by the proposed embankment section on the foundation soils cause shear failure or detrimental settlement?
3. What side slopes are required for stability of the section?

¹
The determination of the constitution, slope and thickness of wearing course, base, subbase and subgrade layers and shoulders, as well as drainage features.

With regard to the highway cross section, the subsurface investigation should furnish information sufficient to answer the following questions:

1. What compaction control should be exercised for the subgrade?
2. Are the subgrade soils sufficiently susceptible to frost action, pumping action, or shrinking and swelling to cause distress of the pavement section? If so, what type of insulation courses are required?
3. What drainage control is necessary to insure continued competence of the highway cross section?
4. Are foundation and subgrade soils compatible with the pavement section proposed?

The problems listed above are not all that may be encountered in the design and construction of the proposed facility. Special problems may arise that require special attention. Only by close liason between the design engineers and those carrying out the subsurface investigation can the proper information be obtained.

For a more complete discussion of the engineering problems related to highway design and construction the reader is referred to references (58), (60), and (64).

Subsurface Investigation Procedures

From either previous experience or from an office study, the soils engineer gains an understanding of the general subsurface conditions within a project area. From his own experience and/or through consultations with the design engineer he can formulate a listing of the particular engineering problems anticipated under these conditions. He

must then formulate a field exploration program that will provide most economically a characterization of these subsurface conditions sufficiently detailed for the solution of the problems at hand. Specifically, he must decide on a method (or methods) to penetrate the various soil and rock layers, establish their limits and borders, and evaluate their ranges in engineering characteristics and properties.

The most common method of soil exploration for highway design and construction purposes is the semi-direct examination of the soil profile by means of a drilled hole or boring, usually advanced with a power driven auger. Hand auger and wash boring methods are also employed. The engineering properties and characteristics are evaluated by performing specific laboratory tests on selected samples. The engineer must therefore determine the location, spacing, and depth of the borings, as well as the type and number of samples to be obtained.

As subsurface conditions and engineering problems vary from area to area, no fixed procedure can be (or should be) specified. However, certain general rules have been established (2), (4), (65), that can be used as a guide in planning exploration programs. These rules are briefly outlined in the following sections.

Spacing and Depth of Borings

Borings are generally located along the centerline(s) of the proposed pavement section(s). In cut or borrow areas, borings should be located such that all material to be excavated is examined.

Borings are spaced according to the following general criteria:

1. If the soil profile is expected to be essentially uniform areally, the spacing is large, although sufficient borings are taken to determine that essential uniformity does obtain.

2. Spacing is small near predicted soil borders and is verified by observed profile changes until it appears that all variations have been mapped.
3. Borings should be closely spaced near transition zones (grade changes from cut to fill) where for example, the extent of coincidence of the grade line with a troublesome plastic soil horizon should be determined.
4. Borings should be concentrated at sites of major loadings, particularly where these coincide (as they often do) with locations of inherently weak or compressible foundation soils.
5. Borings should be staggered to permit definition of possible strata inclination transverse to the route alignment.

The depth to which borings should be carried is a function of the magnitude of the applied loads, the geometry of excavations, the character of subsurface materials, and the possible presence of any inherently undesirable subsurface material or stratification (58, Chp. 11). The following general rules apply to boring depth:

1. Where the stability of the section is in question, the boring should extend to a depth greater than that for the most probable failure surface.
2. Where detrimental settlements are expected, the boring should be progressed to a depth where the stress increase due to the applied load is equal to one-tenth the vertical effective overburden stress or to a firm layer, whichever depth is less.
3. The boring should penetrate the weathered soil horizons and permit examination of the parent material, unless that parent material is quite deep.

4. The boring should extend below the estimated depth of cut or borrow, or to the depth indicated by (1) above, whichever is greater.
5. The boring depth should be such that the drainage appurtenances can be properly designed.

Type and Number of Samples

In addition to delineating the borders and establishing the depths of the deposits within a project area, the engineer must also be able to predict the engineering behavior of these deposits, either in place, or as excavated and compacted. He may either do this directly by performing laboratory tests designed to measure specific engineering properties, or indirectly, and less quantitatively, by simple classification and use of correlations between classification and properties. The classification system used by most highway departments is that established by the American Association of State Highway Officials (AASHO) (2). The Association sought to establish a useful classification of subgrade materials that might be accomplished from a minimal number of simple routine tests. That the AASHO classification (in addition to group index) may supply all the information needed for an adequate, if perhaps conservative, design of pavement sections is demonstrated by its successful use by a number of highway organizations. Design of major cuts, fills, grade separation structures and bridges requires evaluation of the strength and compressibility of the in-situ materials.

Whether specific property measurements are made, or the samples are simply classified, the engineer is still faced with the problem of

extrapolating the data from a few specific locations to cover a volume of soil many, many times that which has been sampled. Present methods of analyzing soil investigation data only allow the engineer to determine the properties and characteristics of the samples taken, and do not clearly define how greatly these properties and characteristics may vary with the deposit. Statistical methods are required to determine the relative homogeneity of a soil deposit, the probable variation of any given measured quantity within the deposit, and the number of samples which must be tested to define a soil property or characteristic to a given degree of precision.

Significant statistical studies in recent years include those by Thornburn and Larsen (50), Morse and Thornburn (42), Hampton (20), Deen (12), and Scott (45). The investigations by Thornburn, Morse, Hampton and Deen sought to determine the number of samples needed to obtain reasonable correlation between pedologic soil types and certain engineering characteristics. The characteristics tested were mainly the liquid and plastic limits and the percentage of clay fraction. Scott's study undertook to determine the relative homogeneity of a soil deposit (defined in an engineering sense rather than pedologically), and for this reason is perhaps a more significant study for highway design purposes. There is some lack of agreement between these studies, due to the different variables isolated and the degree of precision expected. Although a rigorous application of the statistical approach to each project is impractical, such studies on selected soils

do sharpen the engineer's judgement relative to the number of samples required and the probable precision of any given test determination.

Summary

In planning the hypothetical subsurface investigations for the case studies which follow, the location and depth of the field borings were determined guided by the rules listed under "Subsurface Investigation Procedures". In fill areas only routine classification tests will generally be performed since AASHTO classification of materials is usually sufficient to determine the adequacy of the soil as a foundation. The exception is where high embankments are to be constructed on relatively weak or compressible soils, requiring special site investigation. In general, special site investigations will be excluded from discussion in this thesis. In cut areas, in addition to obtaining classification samples, samples for California Bearing Ratio (CBR) and standard compaction tests will be obtained for each distinct deposit within the proposed excavation which is to be used for embankment construction. In materials where compaction control is particularly critical (nonplastic silts, for example) for proper performance of the completed facility, more samples will be obtained and tested than would otherwise be necessary. If the cut is a major one, special site rules for sampling and testing of the material in an essentially undisturbed condition (or of detailed evaluation in-situ for sands) will obtain. In both cut and fill areas, the number of samples taken will depend upon the degree of homogeneity of the deposits.

SELECTION OF PROJECTS FOR DETAILED STUDY

In selecting projects for detailed investigation, the following general criteria were employed:

1. The physiographic units within which the projects were located should represent a significant percentage of the total land area of Indiana.
2. The local physiographic setting should be typical of the physiographic unit.
3. There should be sufficient geologic, pedologic and airphoto coverage to permit a valid office study.
4. There should be completed subsurface investigation reports available for the study area.
5. A section of Interstate Highway should be planned or constructed across the study area.

The locations of the selected projects are shown in Figure 2. The physiographic setting of each of the study areas is described in the following paragraphs.

Case Study 1, Interstate Route 64 Posey, Vanderburgh, and Gibson Counties

The study area intersects the border of the Till Plains Section of the Central Lowland Province and the Aggraded Valley Section of the Interior Low Plateau Province (32). Locally it is situated entirely

After Malott (32)

FIGURE 2. PHYSIOGRAPHIC LOCATION OF STUDY AREAS

within the Wabash Lowland (61). The Lowland, occupying 4900 square miles in Indiana, is characterized by several wide alluvial plains underlain by lacustrine sediments of glacial or post-glacial time. It includes both glaciated and driftless uplands with comparatively smooth topography and an average elevation of 500 feet above sea level. The entire study area is considered to be covered with loess deposits of varying thickness. Thus parent materials in the area are varied, consisting of glacial till of Illinoian Age, loess, alluvial and lacustrine deposits, and residual soils weathered from sedimentary rocks.

Case Study 2, Interstate Route 65
Lake, Newton, and Jasper Counties

The project selected for study lies entirely within the Eastern Lake Section of the Central Lowland Province (32). Locally, it is situated entirely within the Kankakee Lacustrine Unit of the Northern Moraine and Lake Region of Indiana (62). This unit, occupying some 3000 square miles in northwestern Indiana, is characterized by a great system of sandy outwash plains, valley train deposits, and local enclosed till plains, associated with a great line of glacial drainage and ponding along the St. Joseph, Kankakee, Tippecanoe, and Iroquois Rivers. Major parent materials in the area are thus of glacial or glaciofluvial origin. Sand dunes and peat and muck deposits are prevalent.

Case Study 3, Interstate Route 69
Allen County

The study area lies entirely within the Till Plains Section of the Central Lowland Province. Locally, it is situated in the Tipton Till Plain, the largest physiographic unit in the State (occupying 11,900 square miles), which is characteristically a slightly modified ground moraine and is monotonously flat over wide areas. It is traversed by numerous low and sometimes inconspicuous morainic ridges. In the study area the glacial till is distinguished by its high clay and low sand content, differing in this respect from all other Pleistocene units in Indiana (27). Parent materials are fine-textured glacial till, alluvial deposits (washed from this till), and glaciofluvial outwash.

Case Study 4, Interstate Route 70
Henry County

The study area lies parallel to and north of the southern border of the Tipton Till Plain, described in the preceding paragraphs. The till in this area is composed of more granular materials than in the preceding instance. The pedologic soils (Miami-Crosby) are part of the largest soil catena mapped in Indiana, covering 20 percent of the total land area of the state (20). Parent materials in the area are glacial till, alluvium washed from this till, and valley train deposits of glaciofluvial origin.

The local physiography of the individual study areas is typical of the physiographic units in which they are located. For this reason, general conclusions based on intensive study of the individual projects

should apply to other areas within the same physiographic setting. Pertinent information from each of the preceding discussions is summarized in Table 1.

Type of Facility

In all cases the proposed facility is a section (or sections) in Indiana of the nationwide Interstate Defense Highway System. This system when completed will link 300 cities and military establishments with a network of high speed, limited access highways over 41,000 miles in length. The mileage in Indiana alone is over 1,150 miles.

Present standard design in Indiana calls for the construction of two, dual-lane paved roadways, each a minimum of 24 feet in width, separated generally by a wide, sloped, earthen median. This wide median not only provides space for efficient drainage facilities, but also for additional future traffic lanes should increased vehicular flow make such necessary. Both rigid and flexible pavement sections may be used.

All traffic flows in the same direction on each roadway with no at-grade intersections or stop lights. Access is limited to widely spaced interchanges. No encroachments are allowed within the right-of-way.

Special design considerations for the sections discussed are listed in the detailed case study descriptions.

Case Study	Project	County Location	Local Physiographic Unit ¹	Percent of Total Area in Indiana	Parent Materials
1	Interstate Route 64 1 (5) 17, 2	Pozay, Vanderburgh, Gibson	Wabash Lowland	13%	Loess Glacial Drift (Illinoian) Alluvial Deposits Lacustrine Deposits Sedimentary Rocks
2	Interstate Route 65 3 (1) 239	Lake, Newton, Jasper	Kankakee Lacustrine Unit of Northern Moraine and Lake Region	8%	Glaciofluvial Outwash Sands Eolian Deposits (Dunes) Alluvial Deposits Organic Deposits
3	Interstate Route 69 4 (28) 86	Allen	Tipton Till Plain	33%	Glacial Till (Wisconsin) Alluvial Deposits Glaciofluvial Outwash Deposits (Variable) Organic Deposits
4	Interstate Route 70 5 (44) 122	Henry	Tipton Till Plain	33%	Glacial Till (Wisconsin) Alluvial Deposits Glaciofluvial Deposits (Sand and Gravel)

TABLE 1
SUMMARY DESCRIPTION OF SELECTED STUDY PROJECTS

¹ After Malott (32).

² Design or construction section designations.

CASE STUDY 1
INTERSTATE ROUTE 64
POSEY, GIBSON, AND VANDERBURGH COUNTIES

Material used in the preliminary planning of a subsurface investigation for the interstate highway section(s) is summarized by topic in the following paragraphs. In cases where a single reference contributed a substantial portion of the information, it is credited at the beginning of the discussion.

Geology (19)

Four distinct topographic units were identified within the limits of the study area. These units, and the landforms associated with them, were:

1. rugged uplands . . . sandstone-shale hills,
2. rolling uplands . . . loess hills,
3. upland plains . . . lacustrine plains,
4. river flats . . . flood plains.

The last two units were a result of accumulation of unconsolidated material in relatively recent geologic times, while the first two have resulted from the erosion of predominantly hard sedimentary rocks and the deposition of thick mantles of loess.

The border of the Illinoian till sheet crosses the area of interest in a general northeast to southwest direction. The rolling uplands carry only a thin veneer of glacial material and are capped by

moderately thick loess. The valleys contain thick silt deposits which are attributed to turbid discharges from the ice sheet that settled in the glacial lakes. Several stages of valley filling occurred due to advance and retreat of the ice sheet. Loess of various glacial and interglacial stages mantled these deposits. Such loess deposits are the predominant feature of the area, obscuring most of the elements that could be used to distinguish the landforms. For that reason, soil groups within this study area (other than the flood plain) are bounded by topographic units inferred from geologic and pedologic study.

An areal geology map, Figure 3, and a geologic columnar section, Table 2, are presented on the following pages. Detailed descriptions of significant mapped units, arranged in order of increasing geologic age, are presented in the following paragraphs.

Lower Flood Plain and Swamp Deposits (Recent) (19) (57). These deposits consist of silts, sands and fine gravels deposited along the flood plains of present-day streams, with occasional areas of muck and peat occupying broad shallow depressions. Typically, the sediments contain thin and lenticular lithic units of diverse origin which currently are undergoing some degree of accumulation. The thickness of the muck and peat is usually three or four feet, but may reach seven to ten feet.

Iowan Loess Deposits (Quaternary) (19). These deposits consist of a considerable thickness of loess which was deposited as a mantle over nearly the entire surface of Iowa, Illinois, and Indiana. Within Indiana the thickness of this mantle decreases as the distance from the Wabash River increases. Within the study area, these deposits are

Scale = 1:125,000

After Fuller & Clapp (19)

AREAL GEOLOGY MAP

CASE STUDY I

LEGEND

Ci	Inglefield Formation	Q1f	Lower Flood Plain Deposits
Cs	Somerville Formation	Q1 ³	Lake Deposits of the Second Halt
Cd	Ditney Formation	Q1t	Thin Till Sheet

FIGURE 3

System	Series	Stage	Formation or Substage	Description
Quaternary	Pleistocene	Recent	Unnamed	Post-glacial swamp and lower flood plain deposits
		Wisconsin	Iowan	Loess
		Sangamon	Unnamed	Interglacial Loess deposition
		Illinoian	Unnamed	Glacial lake deposits of second halt
			Unnamed	Glacial lake deposits of maximum advance
Pennsylvanian	Conemaugh		Jessup	Glacial till
			Wabash	Interbedded sandstone, shale and coal
			Inglefield	Massive sandstone
			Ditney	Interbedded sandstone, shale and coal
			Somerville	Limestone with shale parting

After Fuller & Clapp (19)

TABLE 2
GENERAL GEOLOGIC COLUMNAR SECTION
CASE STUDY 1

typically ten to fifteen feet in thickness. Also included in this formation are the older stream silts occupying most of the smaller valleys. These consist largely of reworked loess and are markedly clayey.

Glacial Lake Deposits (Quaternary) (19). The drainage of the study area was generally to the west or northwest. When the ice sheet advanced again and lay across the lower portion of the valleys, lakes were created in their upper portion in which large amounts of silts and smaller amounts of coarser material were laid down. These deposits generally accumulated to the level of the standing water. Two distinct glacial lake deposits are mapped within the area of interest. (See Table 2.)

Jessup Formation (Quaternary) (19). In the area under consideration, the matrix of the till consists of a more or less sandy clay which was derived partly from old soils or earlier drift sheets and partly from the grinding and pulverizing of fragments of sandstones, shales, and limestones. The texture of the finer portions of the till varies greatly, depending upon the nature of the rock from which it was principally derived. Where shale appears to have furnished the larger portion of the material, the till is generally very clayey and is of gray or bluish gray color. Where sandstones have furnished much material, the till is sandy, and varies in color from a deep buff in the moderately oxidized portions to deep red in the upper and more strongly weathered parts.

Bedrock Formations (Pennsylvanian) (19). The geologic formations underlying the rugged and rolling uplands belong to the Pennsylvanian

Series. These distinct rock masses, arranged in order of increasing geologic age, are mapped as the Wabash, Inglefield, Ditney, and Somerville formations. Within the study area, Inglefield is the only outcropping formation. These beds, having a regional dip to the west of approximately twenty feet to the mile, are complex, occurring as alternating beds of sandstone and shale with intermingling strata of limestone, coal, and clay. The composition of the individual formations is of interest because this composition directly affects the nature of residuum overlying the rock mass.

Pedology

Agricultural soil surveys of Vanderburgh (54) and Gibson (7) Counties were available for use in the preliminary planning stage in this case study area. Both surveys were acceptable for use in delineating major soil boundaries. (See rating of agricultural soil surveys in Indiana, Appendix B.) For the identification of individual map units (soil types) within the major boundaries, the Vanderburgh County study, which is in accord with present-day standards, was used.

The agricultural soil surveys generally described the geology, physiography, and drainage conditions of the study area. The soil survey identified the same four general topographic units described previously and mapped the following soil associations within these units:

Rolling Uplands	(Silty Upland Soils)	Alford-Muren-Ragsdale
Upland Plains	(Silty Soils of the Lake Plain)	Iona-Ayrshire-Ragsdale

Flood Plain	(Alluvial Soils)	Stendal
	(Slackwater Deposits)	Lyles
Rugged Uplands	(Loess-covered Residual Soils)	Vanderburgh, Zanes- ville, Johnsborg.

Because of the thick loess mantle, silt loam was the predominant surficial texture mapped, although some silty clay loam soils were mapped in the slackwater area of Flat Creek. Typical soil profiles describing major color, texture, and consistency changes, are presented on pages 36 to 39.¹ The relative topographic position, drainage and permeability, and parent material(s) of the soil types mapped are also listed with the profile.

Results of standard laboratory tests (Atterburg limits, grain size analysis) were available for some of the profiles shown (60). Where possible, a general AASHO classification was assigned to the individual horizons. It should be remembered that these classifications are inferred from limited tests and correlation data. Hence classification was not possible for all profiles.

Airphoto Interpretation

The study area is delineated on the assembled uncontrolled photo mosaic, Figure 4. The over-all light photo tone and smooth texture reflect the extent and relative depth of the loess mantle over the entire area. Indeed, without stereoscopic examination, little interpretation could be made based upon photo tone and texture alone. Dark photo tones scattered throughout the study area suggested surficial soils with a high clay content and/or areas where the water table was very near the surface. Specifically, the study area was subdivided as follows.

¹
Condensed from complete soil type descriptions available from the United States Department of Agriculture (USDA).

Alford Silt Loam

Topography - undulating to strongly sloping upland areas in regions of sandstone, shale, and siltstone, and Illinoian drift.

Drainage and Permeability - well drained (16 - 4%), runoff is medium on milder slopes, rapid on steep slopes. Permeability is moderate.

Parent Material - loess, depth to bedrock 8 to 12 feet.

Ragsdale Silt Loam

Topography - depressions and depressed flats in both terrace and upland positions.

Drainage - very poorly drained under natural conditions. Most areas were swampy or ponded. Easily drained artificially.

Parent Material - deep loess.

Iona Silt Loam

Topography - nearly level to gently sloping areas on both upland and terrace positions.

Drainage - moderately well drained (4 - 0%). Surface runoff is moderate and internal drainage is moderate in the upper part and slow in the lower part.

Parent Material - deep loess.

Ayrshire Silt Loam

Topography - nearly level to gently undulating (4 - 0%) areas on both upland and terrace positions.

Drainage - imperfect, low surface runoff; internal drainage is slow due to the natural high water table and to the heavy textured subsoil.

Parent Material - Deep Loess.

Stendal Silt Loam

Topography - nearly level stream bottoms, often that part of floodplain adjacent to upland.

Drainage - imperfectly drained, subject to flooding to a variable degree.

Parent Material - alluvium washed mainly from upland and terrace areas of sandstone, siltstone and shale with some material from glacial drift.

Keyesport Silt Loam

Topography - alluvial fans between the foot of slopes stream bottoms or terraces (colluvial slopes).

Drainage - imperfectly drained because of low gradient, not subject to overflow.

Parent Material - alluvial and colluvial material from silty upland soils subjected to severe erosion.

Lyles Silt Loam

Topography - depressions and depressed flats in old low terraces, especially adjacent to uplands where Alford soils are dominant.

Drainage - very poorly drained; surface runoff is very low with many areas ponded until artificially drained.

Parent Material - lacustrine deposits of weathered alluvium of mixed origin.

Vanderburgh Silt Loam

Topography - moderate to steep slopes in upland areas.

Drainage - very high surface runoff; moderate internal drainage.

Parent Material - thin deposits of loess (16 to 40 in.) over sandstone, siltstone and shale residuum.

Zanesville Silt Loam

Topography - nearly level to strongly sloping uplands dominantly gently sloping and sloping, common gradients are 3 to 8 percent.

Drainage and Permeability - Well drained to moderately well drained. Runoff is medium, permeability moderate to slow.

Parent Material - (moderately deep) Loess mantled residuum.

Johnsburg Silt Loam

Topography - nearly level to undulating areas in relatively broad upland.

Drainage - imperfect, surface runoff is low, very slow permeability.

Parent Material - thin loess and sandstone, siltstone and and shale residuum. Loess mantle 18 to 48 inches thick.

Hosmer Silt Loam

Topography - gently undulating to moderately steep slopes in upland areas. (16 - 4%)

Drainage - well drained, surface runoff is medium to high, internal drainage is moderate.

Parent Material - moderately deep (6 to 10 feet) loess over sandstone, siltstone and shale residuum.

Peoga Silt Loam

Topography - nearly level to slightly depressed areas in low stream terraces.

Drainage - poorly drained surface runoff is very low and internal drainage is very slow.

Parent Material - lacustrine deposits of stratified silt clay and fine sand

LAND FORMS AND ENGINEERING SOIL AREAS

① LOESS-COVERED HILLS (LOESS PROBABLY UNDERLAIN BY TILL SHEET)	③ RIVER FLOOD PLAIN
② DEEP LOESS MANTLE OVER LAGUSTRINE DEPOSITS	④ LOESS-GAPPED SEDIMENTARY ROCK HILLS

FIGURE 4
UNCONTROLLED AIRPHOTO MOSAIC
PROPOSED INTERSTATE ROUTE 64

0 1000' 5000'
SCALE

Rolling Uplands (Stations 970 to 1010, 1126 to 1208).¹ Between these station limits the topography is rolling, land use is intense (farming), slopes and stream gradients are moderate, and gullies, where they have formed, are generally U-shaped. Photo tones are over-all light, with dark tones prevalent in areas of depressed topographic position. Photo interpretation was sufficient to indicate that these are loess-covered hills. Based on the previous geologic discussion, however, and comparing photo patterns between these station limits with those between stations 1208 and 1250, it was further inferred that the loess in this area is underlain by Illinoian glacial till, which in turn is underlain by residual soils weathered from sedimentary rocks. The rolling topography (and other elements) indicated that unconsolidated materials are relatively deep in the above sequence. The areal geologic map, Figure 3, supported the suggested sequence. The inferred AASHO classification of surficial soils was A-4 or A-6 in the light tone areas, and A-6 or A-7 in areas where photo tones were dark.

Upland Plains (Stations 1010 to 1054, 1077 to 1126). Between these station limits the topography is over-all flat, land use is intense, and drainage and other erosional patterns are generally absent (some very wide and very flat gullies were identified). The over-all dark photo tones indicated a high water table and/or fine textured surficial soils. Light photo tones are prevalent on areas of raised topographic position. Topography, land use, and absence of erosional

¹ Approximate station limits. (See Plate 1.)

patterns indicated that the area was occupied by a lacustrine deposit of (Illinoian)¹ glacial origin. Photo tone and textures again reflected a deep loess mantle over the area. It was inferred from topographic position and intensive farming that the area was not subjected to frequent flooding.

Inferred AASHO classification of surficial soils was as noted above under "Rolling Uplands".

Flood Plain (Stations 1054 to 1077). Flat topography, dark photo tone and lack of land use indicated that this area is occupied by the flood plain and slackwater deposits of Flat Creek. It is subjected to seasonal or frequent flooding (indicated by both the geological and pedological studies). Muck and peat deposits described in the geologic discussion were probably obscured by the thick vegetation east of Flat Creek.

The inferred AASHO classification of surficial materials was A-5, or A-7, with high organic content.

Rugged Uplands (Stations 1208 to 1256). Between these station limits the topography is rugged (as compared with previous units), gullies are V-shaped with steep gradients, land use is minimal (predominantly in forest and pasture), and severe wind and water erosion is prevalent. Erosional and land-use features indicated a shallow soil cover, probably loess capping sedimentary rock hills. Pedologic studies confirmed the shallow cover of unconsolidated material and the prevalent silty texture of the surficial material. Geologic studies

¹

Indicated by geologic study.

indicated the area was unglaciated--another reason for the shallow soil cover--and that the sedimentary rocks are predominantly sandstone and shale.

The inferred AASHTO classification of surficial materials is A-4 or A-6.

Engineering Problems

The chief engineering problem anticipated in the study area was that of properly compacting the loessial soils for subgrades and embankments. The texture of these soils (Alford, Ayrshire, Iona, etc.) would make necessary close moisture control, probably at slightly below optimum (64). Too little moisture would result in undercompaction and subsequent poor performance. Higher moisture contents could create a partially "quick" condition in which the soil could not support construction equipment. A considerable number of moisture-density and CBR tests probably should be performed on representative samples.¹ Airphoto studies indicated that slope erosion would also be a problem with these soils.

Residual soils encountered within the study area were, on the basis of past performance, considered adequate for subgrade purposes. To prevent pumping under rigid pavements, insulation courses may be required, particularly in cut areas. Embankments crossing flood plain areas should be constructed well above expected high water levels. Attention to drainage is important throughout the study area.

¹

See page 22.

Design Considerations

The facility to be constructed crosses Vanderburgh County on its northern border and follows a general east-west direction. The grade is largely in fill, although several significant cuts occur. The proposed centerline profile and existing topographic conditions are shown in Plate 1. A high embankment (30 feet) is to be constructed over the New York Central Railroad between Stations 1020 and 1050. Because this embankment is to be situated on the variable lacustrine deposits discussed under "Geology", a special site investigation should be conducted. Ordinary rules for soil surveys concentrating on pavement adequacy would not (and should not) be applicable for this site, hence it was excluded from further consideration. A ten-inch reinforced concrete pavement is proposed for the facility.

Predictions Based on Preliminary Studies

Findings of the photo-geological and pedological studies are summarized and tabulated in Plate 1. Boundaries of the individual topographic units were determined on the basis of contour elevations shown on the geologic map, Figure 3. Borders thus delineated agree closely with those established by airphoto interpretation of the study area. Differences were attributed to (1) the small scale and large (20-foot) contour interval of the geologic map, and (2) the inaccuracies inherent in scaling from an uncontrolled photo mosaic. Specific findings for the topographic units are discussed in detail in the following paragraphs.

Rolling Uplands (Stations 970 to 1010). The geologic study indicated this area to be within the limits of the Illinoian till

sheet, with the till deposits overlain by loess. The sequence of expected parent materials is as tabulated in Plate 1. The zone of illuviation (B-horizon) in loessial soils is characteristically clayey, thus the inferred A-6 or A-7 classification. Limited correlation data available for the Alford Series indicated that the B-horizon material was most likely A-7-6 material. The depth of this material varies from two to four feet, depending on the relative topographic position. Below this depth, loess unmodified by soil forming processes should be found. This material is usually yellowish-brown or light brown silt with a massive structure. Again, correlation studies indicated that the loess is probably A-6 material, although the pedological map shows small quantities of fine sand present with the silt, in which case A-4 would be the inferred classification. There was no indication in any of the studies of the total depth of the loess cover. However, the mantle was expected to be thinner, say four to six feet, on the higher elevations. The glacial till, when encountered, should be A-4 material because of its expected sandy clay texture (inferred from geologic study). This till probably overlies the Wabash formation which is high in claystone and shale content. Residium weathered from this formation is characteristically clayey, thus the inferred A-6 or A-7 classification. The agricultural soil survey for Vanderburgh County (54) indicated the depth to bedrock was eight to twelve feet. Soils in the depressed topographic positions should have a high organic content in their surficial horizon and a clayey B-horizon of four to six feet thickness.

Upland Plains (Stations 1010 to 1126, excluding 1054 to 1077). In this unit the photo-geologic studies indicated a complicated sequence

of lacustrine, fluvial and eolian deposits of great depth. The pedological study indicated that the area had been covered by a thick loess mantle. The thickness of this mantle probably exceeds ten feet on these lake plain deposits. This loess was deposited during the Iowan substage of the Pleistocene epoch and was expected to be relatively uniform with respect to modal grain size and plasticity characteristics. The B-horizon of these loessial soils was again expected to be clayey, probably A-7 material. Parent material, as in the previous section, was classified as A-6. Again, depression soils were expected to have surficial horizons of high organic content and deeper and more clayey B-horizons.

Flood Plain (Stations 1054 to 1077). This area was considered to be one of the most problematic. The alluvial soils of the flood plain had been washed from the silty upland plains and rolling and rugged uplands. Alluvium washed from this type of material is of a definite clayey texture. The geologic study indicated the possibility of occasional muck deposits occurring within the limits of the flood plain. It was anticipated that the depth of organic top soil would vary from six inches in level topographic positions to over one foot in depressed areas. It was considered essential to define closely the limits of the flood plain.

Rolling Uplands (Stations 1126 to 1208). The rolling uplands between these station limits are situated at a lower mean elevation than the rolling uplands between Stations 970 and 1010. Because of this lower topographic position, the loess cover on these uplands was assumed to be deeper. This assumption was substantiated by the

pedological survey which indicated that the same soils were mapped on the upland plains and the rolling uplands between these station limits. This indicated that the depth of parent material on the upland plain and rolling upland positions was similar. There was no indication in any reference of the depth to bedrock in this area. The geologic study indicated that till underlies the loess, probably at a depth greater than six to ten feet. Classification of materials expected in this area has been given on page 45.

Rugged Uplands (Stations 1208 to 1256). The photo-geologic study between these station limits indicated an area of shallow soil cover overlying sedimentary rocks, probably belonging to the Inglefield formation. The pedologic study indicated that the parent material in the area was a thin loess capping a mantle of weathered residuum and bedrock. The agricultural soil survey of Vanderburgh County indicated a usual bedrock depth from six to ten feet, with occasional more shallow covering and even outcroppings on heavily eroded slopes. Residuum encountered in this area has weathered from the predominantly sandy Inglefield formation and is probably less plastic than that encountered between Stations 970 and 1010, thus the inferred A-4 classification. Residuum weathered from claystone or shale, identified by a predominantly gray color is more clayey, probably A-6 or A-7 material.

Proposed Subsurface Investigation

Spacing and Depth of Borings

The general rules governing spacing and depth of field explorations have been discussed under "Subsurface Investigation Procedures",

pages 17 to 22. Reference is also made to the "Requirements for Roadway Soil Survey" of the Indiana State Highway Commission. Based on these general rules, boring locations and depths were selected for the proposed facility. These locations and depths are shown in Plate 1. For this case study, the following general guidelines for boring spacing and depth were employed.

In fill areas on lake plains and rolling uplands, borings were located at intervals of approximately 500 to 800 feet. These were spaced so as to profile all representative topographic positions. In these areas, boring depth of 6 to 8 feet were considered adequate to penetrate and examine the loess parent material.¹ In fill areas on the rugged uplands, borings were concentrated in the most depressed topographic positions.

In cut areas where centerline separation was not greater than 100 feet, borings were located alternately right and left on the roadway centerlines at 300-foot spacings. In transition areas, sufficient borings were planned to accurately determine the depth of the clayey B-horizon. In every cut area, borings were spaced and located so as to adequately examine all material to be excavated and potentially used in embankment construction. (Thus, in some areas where centerline separation was greater than 100 feet, borings were sometimes located in the center of the proposed median.) In cut areas, borings were proposed to a depth considered adequate to determine the supporting characteristics of the foundation (6 to 8 feet below pavement grade) or below the depth of required excavation, whichever was greater.

¹ Depths to unweathered parent material were inferred from pedologic study.

It was considered essential to delineate closely the flood plain limits. For this reason, proposed borings bracketed the expected boundary locations. Because of the variability of materials expected within the flood plain limits, borings were specified alternately left and right on the roadway centerlines at a 200-foot spacing. In this area it was suggested that borings be progressed through weak materials into adequate foundation soils.

In all areas, auger borings and representative samples were considered adequate.

Laboratory Tests

Preliminary studies indicated that close compaction control of the loessial soils would be essential. For that reason, a number of compaction tests were specified--at least one from every significant cut. Since practical compaction water contents are largely controlled by natural water contents, a number of such determinations were also recommended. California Bearing Ratio (CBR) tests were specified to determine strengths of the compacted samples. Statistical studies (52) indicated that samples from the B and C horizons of profiles from 5 depressed and 5 sloping topographic positions should be adequate to classify these soils.

The number and average spacing of borings for each of the topographic (landform) units are itemized in Table 3. Also tabulated are the estimated number and type of laboratory tests for the proposed subsurface investigation program.

<u>Item</u>	<u>Topographic or Landform Unit</u>			
	<u>Rugged Uplands</u>	<u>Rolling Uplands</u>	<u>Upland Plains</u>	<u>Flood Plains</u>
Total Number of Borings	22	24	9	11
Number of Borings Per Mile	24	14	7	25
Average Spacing of Borings (feet)	220	375	775	200
Type of Boring	Auger	Auger	Auger	Auger
Total Number of Classification Tests	10	10	10	4
Total Number of Compaction Tests	4	8	-	-
Total Number of CBR Tests	4	8	-	-
Total Number of Natural Moisture Contents	5	10	10	4

TABLE 3
SUMMARY OF PROPOSED SUBSURFACE INVESTIGATION PROGRAM
CASE STUDY 1

Original Subsurface Investigation Program

Two subsurface investigation reports were available for the study area.¹ The field surveys on which these reports were based were conducted according to the "Requirements for Roadway Soil Survey" of the Indiana State Highway Commission. In accordance with these specifications, borings were generally spaced at 300-foot intervals in both embankment and cut areas and located on the centerlines of the proposed roadways. In cuts under 500 feet in length and in areas where "...weak subsoil was encountered..." (in this case the flood plain area), boring spacings were decreased to 100 to 200-foot intervals. In areas where the centerline separation of the eastbound and westbound roadways exceeded 100 feet, such as in the rugged uplands, borings were spaced at 300-foot intervals on each centerline. Boring depths were governed by the position of the proposed grade line with respect to the existing topography rather than by any feature of the terrain itself.

The specifications under which the existing surveys were conducted required that there be obtained "...sufficient and adequate laboratory samples of each soil type for laboratory analysis to confirm field classification".

The survey reports included a detailed field log of each boring, a tabulation of laboratory test results, and a discussion of the findings of the investigations, together with recommendations relative to design and construction problems.

¹

At the discretion of the writer, no specific reference to these reports has been made in the Bibliography.

The extent of the original investigation, within the station limits of the study area, is summarized in Table 4.

Comparison of Original and Proposed
Subsurface Investigation Programs

The original and proposed investigation programs were compared on the basis of extent, results, and costs.

Tables 3 and 4 summarize the extent of the original and proposed investigation programs. In both, the relative complexity or uncertainty of an individual topographic unit is revealed by the number and spacing of the borings within that unit. Although fewer borings were located in every unit in the proposed survey, as compared to the original, only in the case of the Upland Plains unit is the difference of significance. The preliminary studies indicated that the loess cover was deep and uniform in this area, hence 9 borings were considered adequate. The extent of the laboratory testing was similar, although the writer believes the proposed distribution would yield more usable results.

The most difficult element of the comparison is that of the "concept of the profile" yielded by the original and proposed programs, respectively. The writer carefully studied the field logs available in the reports and selected a "typical" log for each topographic unit in the study area. These logs are presented as Figures 5 and 6. They were compared with the inferred sequence of materials as given in Plate 1. The sequence and classification of unconsolidated materials was in general agreement in each of the topographic units (with an exception as discussed in the following paragraph). The office study

<u>Item</u>	<u>Topographic or Landform Unit</u>			
	<u>Rugged Uplands</u>	<u>Rolling Uplands</u>	<u>Upland Plains</u>	<u>Flood Plains</u>
Total Number of Borings	23	32	20	15
Number of Borings Per Mile	25	18	17	30
Average Spacing of Borings (feet)	100	300	300	175
Type of Boring	Auger	Auger	Auger	Auger
Total Number of Classification Tests	10	21	12	8
Total Number of Compaction Tests	1	7	-	-
Total Number of CBR Tests	1	4	-	-
Total Number of Natural Moisture Contents	10	22	12	11

TABLE 4
SUMMARY OF ORIGINAL SUBSURFACE INVESTIGATION PROGRAM
CASE STUDY 1

Rolling Upland Soils

Rugged Upland Soils

TYPICAL FIELD BORINGS, CASE STUDY 1

FIGURE 5

Upland Plain Soils
(Lacustrine Deposits)

Flood Plain Soils

TYPICAL FIELD BORINGS, CASE STUDY 1
FIGURE 6

did not afford an accurate approach of the depths to bedrock. Preliminary field reconnaissance would probably allow a more correct prediction of these depths.

In a previous section, it was predicted that the loess mantle which covers the area would exhibit certain uniform characteristics. Results of extensive classification tests of samples from the B- and C-horizons of loess-derived soils were plotted on a plasticity chart as shown in Figure 7. That this loess cover is uniform is demonstrated by the grouping of test results from each horizon. The parent material (C-horizon) is less plastic than originally assumed, A-4 or A-6 would be a more correct inferred classification than A-6 or A-7. The B-horizon samples exhibit the clayey texture as expected, and the inferred A-6 or A-7 classification is correct. The writer believes that because of the demonstrated uniformity, extensive sampling is not warranted in this and similar areas.

The costs of the original and proposed programs are compared in Table 5. These costs were computed using the units of the proposed and original investigation programs and weighted unit costs supplied by the state soils engineer. They generally reflect the extent of the survey as discussed previously. Because of fewer borings, anticipated field costs are lower in the proposed program. Laboratory costs, as expected, are nearly equal. Special attention is directed to the relatively low cost per mile for the preliminary office study. In this case study area, a significant net saving is anticipated.

PLASTICITY CHARACTERISTICS OF LOESSIAL SOILS
FIGURE 7

<u>Item</u>	<u>Original Survey</u> <u>(cost per mile)</u>	<u>Proposed Survey</u> <u>(cost per mile)</u>
Preliminary Office Study	-	\$ 150 ¹
Field Boring and Sampling	\$ 1,460	\$ 1,055
Laboratory Testing	\$ 795	\$ 765
Preparation of Report	\$ <u>575</u>	\$ <u>575</u>
TOTAL	\$ 2,830	\$ 2,545
ESTIMATED SAVINGS/MILE		\$ 285
PERCENTAGE REDUCTION IN COST		10%

TABLE 5
COSTS OF ORIGINAL AND PROPOSED
SUBSURFACE INVESTIGATION PROGRAMS
CASE STUDY 1

¹
40 hours at \$15 per hour for four miles.

Summary

Of the various phases in the preliminary investigations for this case, the geologic study was of greatest value. It revealed the complex geologic history of the unconsolidated materials, as well as the nature of underlying bedrock formations. The geologic literature further indicated the complex stratigraphy that could be expected in significant cuts and the consequent increase in investigational effort needed in these areas.

The airphoto study indicated the uniformity and relative depth of the surficial materials and was also of value in understanding the drainage and erosional features of the area, but offered little information relative to the nature of the underlying materials. Of the various topographic units, the boundaries of only the flood plain could be accurately delineated from airphoto patterns alone.

The pedologic study was useful in confirming the borders of the flood plain and unglaciated upland areas, but because of the depth of the loess material, borders between the terrace and glaciated upland positions could not be delineated from the agricultural soil map. The AASHO classification of the unconsolidated materials was interpreted from the pedologic names only where correlation data (such as offered in references 60 and 65) were available.

The cost of the exploration program appears to be controlled by the following factors:

1. A large number of borings was required in the rugged and rolling upland areas where cuts were extensive and materials complex.

2. A large number of classification and other laboratory tests was required to determine the adequacy of the materials from cut areas for subgrade and embankment construction.
3. A large number of borings was concentrated in the flood plain area, both to define its borders and examine the variability of the inherently poor fluvial deposits.

CASE STUDY 2
INTERSTATE ROUTE 65
LAKE, NEWTON, AND JASPER COUNTIES

Geology

As noted in a previous section of this thesis, the study area lies entirely within the Kankakee Lacustrine Section of the Northern Moraine and Lake region of the Central Lowland Physiographic Province. Originally called the Kankakee Marsh (5), the area is characteristically a great treeless plain with an average slope of about 1 to 2 feet to the mile in a westerly direction. The plain is dotted with sand ridges and dunes which rise an average of 20 to 30 feet above the surface.

Three distinct topographic units exist, and these may be directly related to the geology. These units are generally classified as

1. flood plains
2. outwash plains
3. sand dunes and ridges.

The first unit is the result of the accumulation of alluvium in relatively recent geologic times, while the last two are the result of the deposition of sandy glaciofluvial outwash and subsequent reworking by wind action. The glaciofluvial outwash overlies a clayey till of an earlier geologic formation, which in turn overlies massive limestone and dolomite bedrocks of Silurian Age (15). Depth to bedrock within the limits of the study area varies from less than 50 to more than 100 feet (56). A general geologic section is shown in Table 6. The formations listed are described in the following paragraphs. The surficial geology of the study area is shown in Figure 8.

After Wayne (55)

SURFICIAL GEOLOGY MAP

CASE STUDY 2

LEGEND

Lake Sediments (Silt, Clay,
Marl, Peat, & Muck)

Outwash Plain Sediments

Dune Sand

End Moraine (Mostly Till)

FIGURE 8

System	Series	Stage	Formation	Description
Quaternary	Pleistocene	Recent	Martinsville	Flood plains and swamp deposits
		Wisconsin	Atherton	Sandy outwash plains and sand dunes
			Trafalgar	Clayey glacial till
Silurian	Cayuga		Kokomo	Massive limestone

TABLE 6
GENERAL GEOLOGIC SECTION
CASE STUDY 2

Martinsville Formation (Recent). The Martinsville formation is a name proposed by Wayne (57) for silts, sands, and gravels deposited along the flood plains of modern streams and the peaty and calcareous muds (marl) of small lakes and sloughs. Typically, the sediments contain thin and lenticular lithic units of diverse origin, which currently are undergoing some degree of accumulation, and thus are so young that they do not exhibit a zonal soil profile.

Atherton Formation (Pleistocene) (57). This formation includes a group of intertonguing and interrelated unconsolidated sediments that resulted from glacial action, but which were deposited extraglacially. The formation has at least four distinct lithofacies: (1) gravel and sand of glacial outwash deposits (outwash facies), (2) silts, sands,

and clays of glacial lake sediments (lacustrine facies), which commonly interfinger with outwash sediments, (3) sand of dunes derived from and overlying outwash materials (dune facies), and (4) silts and clays of loess deposits (loess facies). Only the outwash and dune facies are mapped within the limits of the study area. The dune facies consist of sand that has been eroded and redeposited by wind action. Because of the sorting action of the depositing agent, a very high percentage of these dune sands, commonly 80 to 90 percent, is medium to fine (0.42 to 0.175 mm) in size (49). The total depth of the outwash sediments probably does not exceed 20 feet (56).

Trafalgar Formation (Pleistocene) (56). This formation is composed of glacially deposited mudstone and associated lenses of clay, silt, sand, and gravel, all of glacial origin. The formation has two distinct members, only one of which is mapped in the study area. The Cartersburg Till Member, believed to underlie the Atherton formation within the study area, consists primarily of conglomeratic sandy mudstone. The total thickness of the formations varies from 20 to 80 feet within the study area.

Kokomo Formation (Silurian) (56). The Kokomo formation is essentially a massive limestone bed 75 to 100 feet thick. Depth to this formation varies from less than 50 feet at the Kankakee River to over 100 feet at the southern extremity of the study area.

Pedology

An agricultural soil survey of Newton County (44) was available for use in the preliminary planning of the subsurface investigation

program. The maps included in the Newton County survey report show the major associations and individual soil boundaries for approximately seventy percent of the study area. The section of the agricultural soil map which includes the study area is shown in Figure 9.

Since the parent material, topography, and other soil forming factors are essentially constant throughout the entire study area, it is felt that valid assumptions regarding pedological soil types can be made for the remaining thirty percent of the study area for which no soil survey report is available by relating pedological soil types to airphoto patterns. This will be discussed in a later section.

As in other agricultural soil survey reports, the text describes generally the physiography, geology, topography, and drainage conditions of the area. Again, these descriptions were in excellent agreement with material summarized in the Geology Section of this case study, and repetition is considered unnecessary.

The soil survey report for Newton County maps the following soil associations within the topographic or landform units identified in the study area:

Outwash Plains	(level to depressed)	Granby-Maumee
Outwash Plains	(dunes and ridges)	Plainfield-Berrein-Dillon
Flood Plains		Griffin

Because of the nature of the outwash material, the predominant surficial texture mapped is fine sandy loam. Organic content of the surface horizon ranges from high to very high in depressed topographic position to negligible in dune facies. Organic deposits are mapped within the limits of the flood plain. Typical soil profiles describing

FIGURE 9. AGRICULTURAL SOIL MAP, CASE STUDY 2

major color and textural changes are presented on pages 69 and 70. As before, the relative topographic position, drainage and permeability characteristics, and parent material for each of the soil types are listed. Again, AASHO classification assigned for the major horizons was inferred from limited laboratory results and correlation data. No inferences are made concerning classification for horizons of the Griffin Series. This series exhibits such a wide range of characteristics and a lack of uniformity that no definite detailed description can be given. Because of its recent formation, a definite soil profile has not developed. It is moderately high in organic content and in places consists of alternating layers of muck and sandy alluvium. This material ranges in thickness from 3 to 8 feet, and rests upon either a sandy or a clay till (44).

Airphoto Interpretation

An uncontrolled photo mosaic of the study area is presented in Figure 10. This mosaic was taken from a strip map of the area prepared by Yeh (62). Yeh divided the area into landform units and further subdivided the landforms on the basis of apparent texture of the soil and relative topographic position. An independent delineation of landforms by the writer agreed with the borders determined by Yeh, and for convenience, the previously prepared mosaic was used.

In general, photo tones are light on topographic highs, grading to gray to dark gray in depressed areas. Natural vegetation is concentrated on crests and ridges and within the river flood plain. The topography is over-all flat with many apparently superimposed

Granby Fine Sandy Loam

Very dark gray to dark brown fine sandy loam; relatively high organic content.

Dark gray loose fine sand, low organic content.

Mottled light gray and yellow loose fine sand.

Gray sand mottled with yellowish brown.

Topography - nearly level to slightly depressed areas in glacial outwash plains and lake plains.

Drainage and Permeability - poorly or very poorly drained, runoff very slow to rapid. Permeability is very rapid.

Parent Material - calcareous loose sand of glaciofluvial outwash plains.

Maumee Fine Sandy Loam

Very dark gray to black fine sandy loam. Organic content high to very high.

Light gray loose fine sand.

Light gray fine sand mottled with yellow and brown.

Topography - depressions and broad depressed flats in glaciofluvial and lake plains.

Drainage and Permeability - very poorly drained; runoff very low. Permeability is very rapid.

Parent Material - calcareous loose sand of glaciofluvial outwash plains.

Plainfield Fine Sand

Litter and humus soil
Grayish brown to light brownish yellow loose sand.

Brownish yellow to pale yellow loose fine sand to sand.

Loose pervious sand on sand and gravel extending to a depth of 15 feet or more.

Topography - nearly level to undulating, sometimes mapped as dune phase.

Drainage and Permeability - excessively drained surface, runoff is low and internal drainage is rapid.

Parent Material - calcareous loose sand of glaciofluvial outwash plains, reworked by wind.

Berrein Loamy Fine Sand

Topography - nearly level to undulating or gently sloping areas on outwash plains, deltas and lacustrine plains.

Drainage and Permeability - moderately well drained. Run-off is very slow. Permeability in the upper strata is rapid.

Parent Material - calcareous loose sand of glaciofluvial outwash plains.

Dillon Fine Sandy Loam

Topography - nearly level to slightly depressed flats in outwash and lake plains.

Drainage and Permeability - very poorly drained; permeability is very rapid. Some ponding may occur.

Parent Material - calcareous loose sand of glaciofluvial outwash plains.

Griffin Loam

Topography - nearly level bottom lands along creeks and rivers.

Drainage and Permeability - surface runoff is slow, internal drainage is slow. Subject to periodic flooding.

Parent Material - alluvium washed from areas of calcareous glacial drift.

LAND

RE 10

AIRPHOTO MOSAIC

STATE ROUTE 65

1

SANDY OU

2

SANDY OU
ORGANIC

3

SAND DUNE

SCALE

5000'

After Yeh (62)

LAND FORMS AND ENGINEERING SOIL AREAS

① SANDY OUTWASH DEPOSITS	④ INCIPIENT SAND DUNE DEPOSIT
② SANDY OUTWASH DEPOSITS, ORGANIC	①7 FLOOD PLAIN
③ SAND DUNE DEPOSITS	①9 MUCK AND PEAT DEPOSITS

FIGURE 10
UNCONTROLLED AIRPHOTO MOSAIC
PROPOSED INTERSTATE ROUTE 65

0 1000' 5000'
SCALE

crests and ridges throughout. The most conspicuous feature, the prevalence of artificial drainageways or ditches, suggested a high water table condition. Three landforms were distinguished and bounded as follows.

Outwash Plains (Stations 100 to 127, 176 to 188, 268 to 376).¹

Between these station limits, the topography is nearly level to slightly depressed. Photo tones are light in level positions, gray to dark gray in depressions. Land use is minimal. Ditches indicate the presence of a high water table. Natural gully erosion is absent but wind erosion is significant. Where drained, the soil is light colored and probably uniformly sandy. Yeh mapped two soil units within these limits, (1)² sandy outwash deposits, and (2)² sandy outwash deposits with organic topsoil of varying thickness.

Reworked Outwash Deposits (Stations 127 to 176, 188 to 268). The topography between these station limits varies from slightly undulating to crested. Photo tones, where not obscured by vegetation, are light. Land use is intensive on nearly level to undulating areas and negligible on crests and ridges. The sandy outwash material has been reworked to varying degrees by wind action. For that reason Yeh delineated two distinct mapping units. These units are (3)² distinct sand dunes or ridges, and (4)² areas of incipient dune formation.

Flood Plain (Stations 376 to 408). Between these station limits the topography is flat, photo tones are dark, land use non-existent.

¹

Station designations are shown on Plate 2.

²

Numerals refer to Figure 10.

Numerous meander scars and abandoned channels indicate periodic flooding. This area is occupied by the channel and flood plain of the Kankakee River. Numerous organic deposits may be expected, especially in old river meanders and sloughs. This area is denoted by (17)¹ on the strip mosaic.

Using pedologic soil keys and agricultural soil survey reports, Yeh inferred general soil profiles for the individual units described in the previous paragraphs. These profiles are not included in this thesis but may be found in Reference 62.

Engineering Problems

The major engineering problems anticipated were those associated with high ground water conditions and the prevalence of organic soils in depressed areas on the outwash plain and on the flood plain. Highway grade lines should be elevated sufficiently to control flooding, frost damage, or other such difficulties. Whatever drainage can be accomplished, can be achieved rapidly because of the high soil permeabilities. Organic soils should be wasted where exposed in excavation. Within and adjacent to the flood plain, organic deposits are expected to be prevalent.

Another problem to be expected is the wind erosion of cut slopes in the sandy soils. This problem may be controlled by planting.

Design Considerations

The facility to be constructed follows a general north-south direction, passing through southern Lake County and crossing the

¹

Number refers to Figure 10.

northeast corner of Newton County into western Jasper County. The grade is almost entirely in fill, with limited cuts through dune ridges. The proposed centerline profile and existing topographic conditions are shown in Plate 2. High embankments are planned for the New York Central Railroad grade separation between Stations 308 and 334 and for the Kankakee River bridge between Stations 370 and 400. Foundation material for the railroad embankment is believed to be uniform sand 15 to 20 feet in thickness overlying clayey till 40 to 80 feet thick (56). This embankment is a site, but may not require extensive exploration. Foundation materials for the bridge approach embankments are alluvial sediments of extreme variability. This site should be investigated in detail.

Predictions Based on Preliminary Studies

Findings on the photo-geological and pedological studies are summarized and tabulated in Plate 2. Boundaries of the individual topographic units or landforms, delineated on the basis of airphoto interpretation, generally agreed with borders shown on the surficial geology map, Figure 8, and the agricultural soil map, Figure 9. Again, differences may be attributed to difficulties in scaling from uncontrolled mosaics and small scale maps. Specific findings within the mapped units are discussed in detail in the following paragraphs.

Outwash Plains (Stations 100 to 127, 176 to 188, 268 to 276). The preliminary studies indicated that the outwash plains consisted of uniform loose calcareous sand 20 feet or more in thickness, underlain by glacial till. Depth to bedrock was expected to be greater than 50 feet. The pedologic study indicated that the depth of organic

surface horizons varied from one to three feet (depth usually depending upon relative topographic position), however, there was no indication in any reference of the actual percentage of organic matter present. Correlation studies (60), (62) indicated the sand was A-2-4 or A-3 material. Engineering problems expected in this area were those associated with high ground water table conditions and with the loose condition of the sands which were to serve as embankment foundations.

Reworked Outwash Deposits (Stations 127 to 176, 188 to 268). The geologic study indicated that the sand in these deposits should be a uniform A-3 material.¹ The pedologic study indicated that some organic material might be expected in the surface horizon of soils in low topographic positions. Generally, the soil profile was expected to be essentially uniform, both areally and with depth. Engineering problems expected in this area were those associated with the proper compaction of uniformly graded sand and with wind erosion of cut slopes.

Flood Plain (Stations 376 to 408). The photo-geologic and pedologic studies indicated the flood plain deposits were the most variable and complex within the study area. Organic pockets of varying thickness were anticipated. Some of these were expected to be concealed by overlying fluvial sediments. The airphoto study indicated that the area was subject to periodic flooding. The engineering problems anticipated were those of locating and removing organic deposits and countering high water table conditions, as well as properly supporting the high embankment and bridge for the river crossing.

¹

Inferred from grain size distribution predicted by Smith and Bieber (49).

Proposed Subsurface Investigation

In general the proposed investigation was planned to emphasize the definition of:

1. The position of the ground water table throughout the area.
2. The depth and areal extent of organic soil deposits.
3. The classification and compaction characteristics of the material to be used in embankment construction.
4. The relative density of the uniformly graded outwash and eolian sands in-situ.

Spacing and Depth of Borings

Because of the predicted depth and areal uniformity of the soil profile in the outwash and dune deposits, few borings were proposed within these landforms. In fill areas, borings were located at intervals of 500 to 1000 feet, alternately right and left on the proposed roadway centerlines. Borings were generally located in topographic lows because soils in these areas were expected to contain the highest percentage of organic material. Borings in these areas penetrated to a depth equal to the height, and permitted examination of the weathered horizons and parent material. A single boring was continued to rock under the railroad embankment.

In cut areas, spacing was decreased to 300 to 500 feet, and borings were so located that all soil types to be used for embankment construction were sampled and classified. In these areas the depth of exploration permitted adequate identification of the parent material to a depth greater than the limits of the proposed excavations.

Auger borings were generally considered adequate in all areas except for the railroad embankment. For the latter, split spoon samples and penetration resistance ratings would be recommended in the sand and thin-walled tube sampling in the underlying till deposit.

Laboratory and Field Tests

Classification tests were limited primarily to representative samples from cut areas. Visual classification was considered adequate in embankment areas, although a few samples were to be obtained for laboratory classification. Evaluation of in-situ relative density by means of the standard penetration test was recommended for certain areas of embankment foundation. Compaction and CBR tests were proposed for selected samples from cut or borrow areas.

The number, average spacing, and type of borings in each of the topographic or landform units are itemized in Table 7. Also tabulated are the estimated number and type of tests for the proposed subsurface investigation program.

Original Subsurface Investigation Program

A detailed subsurface investigation report¹ was available for the study area. The field survey was in general similar to that outlined in Case Study 1, although the spacing of the borings, as indicated in Table 8, was less than that specified in the State requirements.

Classification of the samples was chiefly visual, although 22 samples were used for laboratory testing. The classification was

¹

See footnote page 51.

<u>Item</u>	<u>Topographic or Landform Unit</u>		
	<u>Outwash Plain</u>	<u>Reworked Outwash Deposits</u>	<u>Flood Plain</u>
Total Number of Borings	19	17	
Number of Borings Per Mile	7	7	(Area to be
Average Spacing of Borings (feet)	750	750	investigated
Type of Boring	Auger ¹	Auger	as a site)
Total Number of Classification Tests (Mechanical Analysis)	5	10	
Total Number of Compaction Tests	1	3	

TABLE 7
SUMMARY OF PROPOSED SUBSURFACE INVESTIGATION PROGRAM
CASE STUDY 2

1

Except in the area of the proposed embankment over the railroad, where cased borings with Standard Penetration Tests are recommended.

<u>Item</u>	<u>Outwash Plain</u>	<u>Topographic or Landform Unit</u> <u>Reworked Outwash Deposits</u>	<u>Flood Plain¹</u>
Total Number of Borings	69	82	16
Number of Borings Per Mile	25	34	27
Average Spacing of Borings (feet)	200	150	200
Type of Boring	Auger	Auger	Auger
Total Number of Classification Tests (Mechanical Analysis)	9	13	5
Total Number of Compaction Tests	1	1	-
Total Number of CBR Tests	1	1	-
Total Number of Loss on Ignition Tests	3	7	2

TABLE 8
SUMMARY OF ORIGINAL SUBSURFACE INVESTIGATION PROGRAM
CASE STUDY 2

1

These units are listed for information only and were excluded in cost comparisons.

based on mechanical analysis, all samples being non-plastic. Two samples each were obtained for compaction and CBR tests. These samples were obtained in cut areas.

The report included a detailed field log of each boring, tabulations of laboratory test results, and a discussion of the findings of the investigation, together with recommendations relative to design and construction problems.

The extent of the original subsurface investigation program within the station limits of the study area is summarized in Table 8.

Comparison of Original and Proposed
Subsurface Investigation Programs

The extents of the proposed and original surveys are shown in Tables 7 and 8. Because of the uniformity of the soil profile within the outwash plain and reworked outwash deposits (predicted from preliminary studies and confirmed by an examination of the logs of field borings), the number of borings taken in the original survey seems generous. A lesser number of borings as proposed would have allowed an adequate sampling and examination of the soil profile.

Laboratory testing is more extensive in the proposed survey, especially with respect to in-situ and compacted densities. Classification tests are concentrated in cut areas (where materials are to be used in embankment construction). There was no indication in the original survey of the in place density of materials in the outwash plain and dune areas. Because the geologic study indicated these materials might be in a "loose" state, the proposed survey included

Standard Penetration Tests in embankment foundation areas. The writer believes that these tests might indicate special design features or construction procedures were desirable.

"Typical" field logs for each mapped topographic unit are shown in Figure 11. These logs may be compared with the inferred sequence of materials shown in Plate 2. The sequence and classification of the materials is in general agreement in each of the topographic units. The depth to glacial till, as indicated in the field borings, varies from the predicted depth by 15 to 20 percent.

In a previous section it was predicted that the granular materials in the reworked outwash deposits would be a uniform A-3 material with a modal grain size between 0.42 and 0.175 mm. The veracity of this prediction is demonstrated in Figure 12. The grain size curves for all classification samples within the reworked outwash deposits fall within the narrow band shown in the figure. It was not possible in this instance to determine if the results displayed any horizon grouping.

The costs of the original and proposed programs are given in Table 9. These costs generally reflect the extent of the surveys as previously discussed. Because of fewer borings, field boring and sampling costs in the proposed program are lower. Even though more compaction tests and in-situ density ratings are proposed, testing costs are nearly equal because of a reduction in classification tests. Again, the cost per mile of the preliminary office study is a small percentage of the total investigation cost. As in Case Study 1, a net saving is anticipated in the proposed program.

TYPICAL FIELD BORINGS, CASE STUDY 2

FIGURE 11

U. S. Standard Sieves

GRAIN SIZE DISTRIBUTION, OUTWASH AND DUNE SANDS, CASE STUDY 2
FIGURE 12

Item	Original Survey (cost per mile)	Proposed Survey (cost per mile)
Preliminary Office Study	-	\$ 100 ¹
Field Boring and Sampling	\$ 655	\$ 315
Laboratory Testing	\$ 115	\$ 130
Preparation of Report	\$ <u>575</u>	\$ <u>575</u>
TOTAL	\$ 1,345	\$ 1,120
ESTIMATED SAVINGS/MILE		\$ 225
PERCENTAGE REDUCTION IN COST		17%

TABLE 9
COSTS OF ORIGINAL AND PROPOSED
SUBSURFACE INVESTIGATION PROGRAMS
CASE STUDY 2

¹
30 hours at \$15 per hour for four and one-half miles.

Summary

In this study area the geologic investigation was of value in indicating the unique geologic history of the unconsolidated materials. This phase of the study was also useful in indicating the general texture of these materials, and predictions of material classification based on geologic references were in close agreement with laboratory test results.

The airphoto study was of great value in delineating landform borders (based mainly on topography), and in locating areas where surface soils might contain a high organic content. Again, the general drainage and erosional features of the area were revealed by the airphoto study.

The pedologic study confirmed the general uniformity of the parent material. The AASHTO classification of materials inferred from the pedologic study via correlation data (mainly from reference 60) closely checked the original investigation values.

As compared with Case Study 1, the cost of the investigation is small. The factors responsible for this low cost are:

1. The general uniformity both areally and with depth of the soil profile in the two major topographic units.
2. The level topography, requiring few cuts or other areas of potentially intensive examination.
3. The granular texture, minimizing laboratory testing.

LE — INTERSTATE ROUTE 65 TON, & LAKE COUNTIES

CASE STUDY 3
INTERSTATE ROUTE 69
ALLEN COUNTY

Geology

The surficial deposits within the study area are of glacial or post-glacial origin. The general boundaries of these deposits and the suggested formation names (55) are shown in Figure 13. The Wabash Moraine, which occupies a large percentage of the area, is one of a series of low terminal moraines formed by the halting retreat of the last continental ice sheet to cover the state of Indiana. The till sheet between the terminal moraines is characteristically level. The material in both the terminal and ground moraines is of a marked clayey texture (27). This material overlies materials deposited by earlier glacial advances.

The bedrock which underlies the unconsolidated deposits is predominantly a massive limestone, which may explain the clayey texture of at least the older till sheets. Bedrock depths vary from less than 150 to more than 250 feet (56).

The plain to the east of the area is a broad level lakebed of glacial times. As the ice sheet retreated eastward, meltwater and surface runoff was impounded between the ice sheet and the Fort Wayne Moraine to the west. This formed an ice marginal lake, Lake Maumee, which grew in size as the ice withdrew. The overflow of this lake was channeled through a saddle in the Fort Wayne Moraine, where it combined

After Wayne (55)

SURFICIAL GEOLOGY MAP

CASE STUDY 3

LEGEND

Lake Sediments (Silt, Clay, Marl, Peat, & Muck)		End Moraine (Mostly Till; Includes Small Areas of Ice Contact Drift)
Valley Train and Outwash Plain Sediments		Ground Moraine (Mostly Till)

FIGURE 13

with the waters of the St. Mary's and St. Joseph's Rivers to form the "Maumee Torrent," which eroded a broad, flat-bottomed channel referred to as the Wabash sluiceway (29). As the ice receded, the Wabash sluiceway received less and less overflow until it carried only the surface runoff from the adjacent uplands.

Post-glacial stream erosion has cut channels 10 to 25 feet below the original flood plains. Alluvial deposits have accumulated along the streams, and muck and peat have formed in the depression and marshy areas along old stream channels. The area can be divided into three main topographic units, all of which are the result of glacial or fluvial action. These units, and the landforms associated with them, are:

1. level to sloping uplands . . . Wisconsin ground or ridge moraine
2. stream valleys . . . local terraces and flood plains
3. level uneroded plains . . . outwash plains.

The Wabash Moraine forms unit one, while unit two is the result of recent fluvial erosion of the till sheet and deposition of stream carried sediments. The outwash plain is the Wabash sluiceway described in a previous paragraph.

A geologic columnar section of the surface and subsurface deposits of the area is presented in Table 10. Detailed descriptions of the formations listed are presented in the following paragraphs.

System	Series	Formation	Description
Quaternary	Pleistocene	Martinsville	Lower flood plain and organic swampy deposits
		Atherton	Valley train and outwash sediments
		Largo	Clayey glacial till
		Trafalgar	Clayey glacial till
		Jessup	Clayey glacial till
Silurian	Cayugan	Huntington	Massive limestone

TABLE 10
GENERAL GEOLOGIC COLUMNAR SECTION
CASE STUDY 3

Martinsville Formation (Quaternary). Martinsville is the formation name suggested by Wayne (56) for silts, sands and gravels deposited along the flood plains of modern streams, and the peaty and calcareous muds of small lakes and sloughs. Within the study area, this formation is found as deep marl and peat deposits within the flood plain of the Wabash sluiceway.

Atherton Formation (Quaternary). This formation consists of unconsolidated sediments that resulted from glacial action but were deposited extraglacially. These sediments (gravel, sand, silt, and

clay) all were derived primarily from glacial outwash and were sorted and deposited by meltwater currents. Within the study area, these deposits are confined to the Wabash sluiceway.

Largo Formation (Quaternary) (56). The Largo formation is divided into three parts. The easternmost of these three parts is designated the New Holland Till member. (See Figure 1.) This till consists dominantly of clay-rich mudstone that is only slightly pebbly. The unit varies in thickness, but the general thickness is less than 75 feet.

Trafalgar and Jessup Formations (Quaternary). Underlying the New Holland Till at a depth of 50 to 75 feet are till deposits of earlier glacial periods. Like the surficial till, these deposits are very clayey in texture (56).

Huntington Formation (Silurian). The nature of the bedrock formation, because it underlies the area at such great depth, is of academic interest. Basically, it is a massive limestone formation 75 to 100 feet in thickness (15).

Pedology

The soil survey report available for Allen County (29) is of questionable value in planning a subsurface investigation. (See Appendix B.) Although the significant soil boundaries are believed to be accurately located, many soil names and soil correlations are not in accord with present nomenclature.

However, with the use of this and other soil survey reports, soil associations within the study area were defined and delineated. The

associations are shown diagrammatically in Figures 14 through 16.¹ The series within these associations are defined on the basis of topographic position, parent material, drainage characteristics, and so forth (50). The series associated with the topographic and landform units defined in the geologic discussion are listed as follows:

Wisconsin Ground or
Ridge Moraine

Morley-Bount-Pewano

Alluvial Deposits

Genesee-Eel-Martinsville

Outwash Plain

Lewanee-Toledo-Mahalasville.

Carlisle and Wellette organic soils are found in depressions within the Little Wabash Valley. The predominant surficial textures within the study area are silt loam or silty clay loam (27). Typical soil profiles for the major soil types within the area are presented on the following pages. Again, AASHO classifications of the individual horizons are inferred from limited laboratory test and correlation data.

Airphoto Interpretation

An uncontrolled airphoto mosaic of the study area is presented in Figures 17 and 18. Five soil-landform units, four of which are of interest in this study, have been delineated on the basis of topography, tone, texture, and other interpretive elements. Some general features may be noted. Over-all the photo tone is mottled, with the gray mottles predominating. The over-all drainage pattern is coarse

1

These figures have been prepared for a new agricultural soil survey report for Allen County which is to be published in 1966.

FIGURE 14. SOIL ASSOCIATIONS OF THE EIGHT MILE CREEK AND PLEASANT RUN AREA.

FIGURE 15. SOIL ASSOCIATIONS OF THE UPLANDS.

Association

- Carlisle, Willette — Depressional organic soils
Lewanee, Toledo, etc. — Very poorly drained lacustrine and outwash soils
Spinks, Mahalasville — Well to excessively drained outwash soils

FIGURE 16. SOIL ASSOCIATIONS OF THE LITTLE WABASH RIVER VALLEY.

Genesee Silt Loam

Dark grayish brown silt loam.

Light yellow to brown silt loam to silty clay loam; thin layer of fine sandy material may be present.

Yellowish brown sand to silty clay.

Topography - nearly level areas in streams and river bottoms.

Drainage and Permeability - well drained, runoff is slow. Permeability is moderate. Areas are subject to flooding.

Parent Material - alluvium derived principally from calcareous glacial drift of Wisconsin Age.

Eel Silt Loam

Dark grayish brown silt loam.

Brown silt loam to loam.

Dark yellowish brown silt loam or loam (mottled).

Topography - nearly level to depressed areas in stream and river bottoms.

Drainage and Permeability - Moderately well drained, runoff is slow to very slow. Permeability is moderate. Areas are subject to flooding.

Parent Material - alluvium derived mainly from medium textured highly calcareous glacial till of Wisconsin Age.

Martinsville Silt Loam

Dark grayish brown silt loam.

Dark brown silt loam.

Dark brown to reddish brown silty clay loam or clay loam.

Reddish brown loamy sand.

Yellowish brown sand with thin strata of sandy clay loam and silt.

Topography - nearly level to sloping areas on stream terraces.

Drainage and Permeability - well drained, runoff is medium. Permeability is moderate.

Parent Material - stratified calcareous sands and silts.

Pewamo Silty Clay Loam

Topography - nearly level to depressed areas in till plains and moraine areas.

Drainage and Permeability - imperfectly drained, runoff is slow. Permeability is slow.

Parent Material - calcareous glacial till of Wisconsin Age. Clay content greater than 28%.

Toledo Silty Clay

Topography - nearly level to depressed areas in lacustrine areas.

Drainage and Permeability - poorly to very poorly drained, runoff is very slow to ponded. Permeability is very slow to slow.

Parent Material - calcareous beds of lacustrine and outwash clay and silty clay.

Mahalasville Silty Clay Loam

Topography - depression and depressed flats in glacio-fluvial outwash plains, often in old glacial channels.

Drainage and Permeability - very poorly drained, runoff is very slow. Permeability is very slow due to natural high water table.

Parent Material - stratified sand and silt, with some gravel and clay of glacio-fluvial outwash plains.

LANDSCAPE 17

AIRPHOTO MOSAIC

①

ALLUVIAL FAN STATE ROUTE 69

5000'

SCALE

LAND FORMS AND ENGINEERING SOIL AREAS

① ALLUVIAL DEPOSITS	② WISCONSIN GROUND MORaine

FIGURE 17
UNCONTROLLED AIRPHOTO MOSAIC
PROPOSED INTERSTATE ROUTE 69

0 1000' 5000'
SCALE

LANDRE 18

AIRPHOTO MOSAIC

(2)

WISCO
MORAI

(3)

LACUS

STATE ROUTE 69

5000'

SCALE

LAND FORMS AND ENGINEERING SOIL AREAS

② WISCONSIN GROUND MORAINES	④ SANDY OUTWASH DEPOSITS
③ LACUSTRINE DEPOSITS	⑤ ORGANIC DEPOSITS

FIGURE 18
UNCONTROLLED AIRPHOTO MOSAIC
PROPOSED INTERSTATE ROUTE 69

0 1000 5000'

SCALE

dendritic, except on the flood plain where natural drainage patterns are absent. The topography of the area varies from plane to gently undulating to softly rolling. Land use in the area is intensive with few areas left in natural vegetation. Specific landforms within the study area are described in detail in the following paragraphs.

Wisconsin Ground or Ridge Moraine (Stations 477 to 836).¹ The topography is plane to gently undulating between Stations 630 to 750, and gently undulating to softly rolling from Stations 477 to 630 and 750 to 836. Drainage in these areas is a poorly developed dendritic system with long "saucer-shaped" gullies throughout. The predominance of gray in the mottled photo tone suggests a high clay content in the surficial soils, probably A-6 material. A previous airphoto study of the area (27) has identified this particular landform as the Wabash Moraine, a terminal moraine of the Wisconsin glacial period.

Alluvial Deposits (Stations 482 to 490, 576 to 578, 768 to 777). Between these station limits, streams have downcut into the till sheet which covers the area. Within the confines of these narrow valleys, deposits of alluvium consisting of stratified sand, silts, and clays have been deposited. In the stream valley northwest of the study area at about Station 550, an active gravel pit may be observed. This suggests the presence of granular materials in these valleys.

Outwash Plain (Stations 836 to 896). Between these station limits, the topography is over-all flat. Dark photo tones and some evidence of artificial drainage suggest the presence of a high water table. The dark photo tones also suggest clayey surficial soil with a

¹

Excluding Stations (482 to 490), (576 to 588), and (766 to 777).

possible high organic content. Sand, gravel, silt, and clay lenses can be expected at depth throughout this area.

Organic Deposits (Stations 896 to 915). The over-all dark photo tones and complete lack of land use suggest the presence of deep organic deposits between the above station limits.

An extensive airphoto and laboratory study of the Wisconsin till in this area has been made by James (27). He lists the results of laboratory tests performed on soil samples from areas having similar airphoto patterns. He concludes that the till in this area is indeed more clayey than expected in other areas of Indiana.

Engineering Problems

The major engineering problems anticipated in the study area were those associated with soils derived from the clayey glacial till. These soils may afford only marginal support when saturated and will probably pump unless the design specifically counters this tendency. Proper compaction of these soils, because of clay content and high natural moisture content, may also be difficult.

Few problems were anticipated with soil deposits within the stream valleys. These soils were believed to be predominantly non-plastic.

Occasional deep organic deposits were expected within the limits of the outwash plain. These deposits should be removed and wasted where encountered.

Attention to drainage is important throughout the study area.

Design Considerations

The facility to be constructed crosses Allen County in a southwest to northeast direction. The route is to be constructed largely in fill although several shallow cuts are proposed. The proposed centerline profile and existing ground line are shown in Plate 3. An embankment 30 feet in height is proposed over the Lake Erie, Wabash, and St. Louis Railroad between Stations 896 and 915. Because of the anticipated nature of the foundation materials between these station limits (stratified silts and clays with occasional organic deposits), the area should be investigated as a site. Embankment height must be maintained above anticipated flood stage in the Little Wabash River Valley.

Predictions Based on Preliminary Studies

The findings of the photo-geological and pedological studies are summarized and tabulated in Plate 3. The borders of the individual areas were delineated on the uncontrolled airphoto mosaic and are in general agreement with those shown on the surficial geology map, Figure 13. Errors were attributed to the small scale of the surficial geology map and inaccuracies in scaling from an uncontrolled mosaic. Observations on soil conditions within each of the mapped areas are discussed in the following paragraphs.

Wisconsin Ground or Ridge Moraine (Stations 477 to 836).¹ The photo-geologic study indicated that the glacial till which is the

¹ Excluding Stations (482 to 490), (576 to 588), and (766 to 777).

parent material of these landforms has a high clay content. The pedologic study indicated that the predominant surficial textures were silt, loam, or silty clay loam, and further that the B-horizon was relatively shallow, seldom exceeding a thickness of 36 inches. From the limited correlation data available, the inferred AASHTO classification of the B-horizon materials was A-7, and of the C-horizon materials, A-6 or A-7-6. A relatively high organic content was anticipated in the A-horizons of soils in depressed topographic positions. The permeability of these soils is very low, and high water contents were expected.

Alluvial Deposits (Stations 482 to 490, 576 to 578, 768 to 777).

The pedologic study indicated that materials within the small stream valleys consisted of alluvium washed from the upland area. The study further indicated that the principal surficial textures would vary from silt loam to sandy loam, hence an A-4 classification was inferred. The gravel pit observed in airphoto study indicated that producible deposits of A-2 and other granular soils might be expected within these valleys. In the smaller stream valleys, silty clay loam would be the predominant texture, and material classification would be A-6 or A-7. For the above reasons, no construction problems, except possibly flooding, were expected.

Outwash Plain (Stations 836 to 896). The materials within the limits of the outwash plain were expected to be complex. The geologic study indicated the possibility of many intertonguing layers of sand, silts, and clays within the Wabash sluiceway. The pedological study indicated that the principal soil association was composed mainly of

the Lewanee and Toledo soils. Both of these soils are dark colored and very poorly drained but differ in clay content. The Lewanee soils (0 - 1% slope) are developed from a silty clay loam parent material, whereas the Toledo soils (depression) are developed from a silty clay or clay parent material. Thus, the classification of the materials was inferred as A-4 or A-6 in sloping positions on the lake plain (Stations 836 to 840) and A-6 or A-7 in the level or depressed positions. The pedologic study indicated that the depth of highly organic topsoil in this area varied with topographic position, but was seldom expected to exceed two feet.

Organic Deposits (Stations 896 to 915). Both the pedologic and airphoto studies indicated the presence of deep organic deposits within the Little Wabash River Valley. The geologic study also suggested these deposits. There was no definition in any reference of their depth, although the pedologic study suggested that this depth exceeded 42 inches.

Proposed Subsurface Investigation

Spacing and Depth of Borings

The locations and approximate depths of proposed borings, shown in Plate 3, were selected on the basis of the general rules governing spacing and depth of field explorations discussed on pages 17 to 22.

In cut areas, borings were usually located alternately right and left on the roadway centerlines at 300-foot spacings, although where cuts were large, borings were also located on the centerline of the proposed median. In transition areas (cut to fill) borings were

located to define adequately the depth of the clayey B-horizon. In all cut areas, borings would be progressed to a depth adequate to determine the characteristics of the foundation soil or to a depth greater than proposed excavation limits, whichever was greater.

In fill sections in the ground and ridge moraine areas, enough borings were proposed to insure that the profile could be adequately sampled. In these areas, borings were located generally in depressed topographic positions since these areas were considered the most problematical. A spacing of 500 to 800 feet was considered sufficient for these purposes.

In the outwash plain area, the nature of the material was expected to depend upon topographic position. Sandy clays were expected on sloping areas, and silty clays and clays were expected in level and depressed areas. Spacings of 300 to 400 feet were maintained. If an areally uniform profile was revealed, spacing was allowed to increase. If large organic deposits were discovered within the outwash plain, soundings would be necessary (on a 100 to 200-foot grid) to determine the quantity of inferior material to be wasted.¹

In stream valleys, at least one boring would be carried into the till parent material which underlies the alluvial deposits.

In all areas, auger borings were considered adequate.

Laboratory Tests

Of the two major areas delineated in the preliminary study (till and outwash), the outwash sediments are expected to be the most variable. One could view the outwash situation as requiring many

1

Following established Indiana practice for defining the extent of highly organic deposits which will be excavated and wasted.

classification samples. It is viewed somewhat differently here in that a significant number of borings and samples are suggested, but relatively few classification tests. It is proposed that visual classification is sufficient with but limited classification testing on what appear to be extreme or limiting samples. It is also important to examine the samples for purposes of defining the presence of any sizeable organic layers or pockets.

Because of its unique geologic history, the till sheet should exhibit certain uniform characteristics. Investigators (42), (45), and (52) have shown that classification properties of glacial till show certain statistical grouping, but fail to agree on the number of samples necessary to define statistical averages within accepted degrees of accuracy. The C-horizon or parent material should show less scatter than the A or B-horizons. It should be possible by selective sampling from areas of alternately high and low topographic positions to define an average classification for the till material. Classification tests performed on representative samples taken for compaction and CBR tests should be adequate to define this average. Compaction and CBR tests should be performed on representative samples from each major horizon exposed in every cut area. As in Case Study 1, since practical compaction water contents are largely controlled by natural water contents, a number of such determinations was also recommended.

The proposed exploration and testing program is summarized in Table 11.

<u>Item</u>	<u>Topographic or Landform Unit</u>			<u>Deep Organic Deposits</u>
	<u>Wisconsin Ground or Ridge Moraine</u>	<u>Outwash Deposits</u>	<u>Alluvial Deposits</u>	
Total Number of Borings	84	15	11	(Soundings
Number of Borings Per Mile	14	13	19	required in this area)
Average Spacing of Borings (feet)	375	400	275	
Total Number of Classification Tests	20	6	4	
Total Number of Compaction Tests	20	-	-	
Total Number of CBR Tests	10	-	-	
Total Number of Natural Moisture Contents	30	6	4	

TABLE 11
SUMMARY OF PROPOSED SUBSURFACE INVESTIGATION PROGRAM
CASE STUDY 3

Original Subsurface Investigation Program

Two subsurface investigation reports were available for the study area.¹ The field surveys on which these reports were based apparently were not conducted according to the requirements described in the previous case studies. The boring interval, as indicated in Table 12, is less than that now specified by the Indiana State Highway Department, and the number of classification tests is quite generous also. The circumstance that led to this rather large exploration effort is unknown to the writer. However, the field logs indicate that the problem situations apparently anticipated were not encountered in the subsurface. Another unusual feature of the investigation is the unusually large number of unconfined compression tests. Again, the reason for this large number of tests is unknown to the writer.

The survey reports contain detailed field logs of each boring, a tabulation of all laboratory test results, and a discussion of the findings of the survey, together with recommendations relative to design and construction problems.

The extent of the original subsurface investigation program within the station limits of Case Study 3 is itemized in Table 12.

Comparison of Original and Proposed Subsurface Investigation Programs

The extent of the proposed and original subsurface investigation programs is shown in Tables 11 and 12. As indicated above, the field boring and sampling program carried out in the original survey

¹

See footnote page 51.

<u>Item</u>	<u>Topographic or Landform Unit</u>			
	<u>Wisconsin Ground or Ridge Moraine</u>	<u>Outwash Deposits</u>	<u>Alluvial Deposits</u>	<u>Deep Organic Deposits</u>
Total Number of Borings	129	55	15	(Sounded on a
Number of Borings Per Mile	21	48	26	100-foot grid)
Average Spacing of Borings (feet)	250	100	200	
Total Number of Classification Tests	122	39	8	
Total Number of Compaction Tests	7	-	2	
Total Number of CBR Tests	3	-	1	
Total Number of Natural Moisture Contents	122	39	8	
Total Number of Unconfined Compression Tests	88	7	-	

TABLE 12
SUMMARY OF ORIGINAL SUBSURFACE EXPLORATION PROGRAM
CASE STUDY 3

seems extensive. In the original survey, the boring interval in the moraine and alluvial areas is similar, while in the proposed survey the boring interval in the alluvial areas is decreased due to the expected variability of these deposits. In the outwash deposits, the proposed investigation employs a spacing of 400 feet as opposed to the 100-foot interval of the original investigation.

The number of laboratory classification tests in the proposed survey, selected on the basis of statistical studies (discussed in previous sections), exceeds the minimum number suggested in any of those studies for a till derived soil. Compaction and CBR tests are more extensive in the proposed survey. The writer believes that the variability of subgrade and embankment materials requires close compaction control.

"Typical" logs of actual field borings are shown in Figures 19 and 20. These may be compared with the inferred sequence and classification of materials shown in Plate 3, and with the predictions based on the preliminary studies. There was close agreement in the Wisconsin ground and ridge moraine units. In the alluvial areas, materials were in general less fine textured than expected. In the outwash areas, materials at depth were more granular than predicted, especially in sloping positions. The thickness of the organic surface horizon in the outwash areas was greater than expected.

Results of 50 classification tests from samples taken within the station limits of the moraine units are plotted in Figure 21. These results show definite grouping, especially in the C-horizon samples. The writer believes that this grouping demonstrates the predicted

Ridge Moraine
(Sloping Uplands)

Sta. 608

Ground Moraine
(Level Uplands)

Sta. 721

Outwash Deposits
(Sloping)

Sta. 840

TYPICAL FIELD BORINGS, CASE STUDY 3
FIGURE 19

Deep Organics

Alluvial Deposits
(Terrace Position)

Outwash Deposits
(Level or Depressed)

Sta. 902

Sta. 485

Sta. 860

TYPICAL FIELD BORINGS, CASE STUDY 3

FIGURE 20

PLASTICITY CHARACTERISTICS OF
MORLEY-BLOUNT-PEWAMO ASSOCIATION
GLACIAL TILL SOILS OF THE WABASH MORaine
FIGURE 21

uniformity of the glacial till parent material. The scatter in B-horizon samples is caused by differences in the topographic position of the profiles from which the samples were obtained.

The costs of the original and proposed surveys are itemized in Table 13. Although the cost of the proposed survey is less than the original, if the original survey had been conducted according to the present requirements (used in Case Studies 1 and 2) the writer believes that the difference would be negligible.

Summary

In the preliminary investigations for this study area, the geologic and airphoto studies were of greatest value. The geologic study indicated that the glacial till in the area was fine textured and of unique origin. The airphoto study indicated the extent of the fine textured till, and the apparent surficial soil classification. Because materials in each landform unit contrasted sharply, landform borders could be clearly delineated on the uncontrolled airphoto mosaic.

Because no reliable agricultural soil survey report or map was available for the study area, the pedologic study was of limited value. The correlation data that were available for the agricultural soil series of the area permitted inference of AASHO classifications for some of the profiles.

The costs of the proposed exploration program are affected, at least in part, by the following factors:

Item	Original Survey (cost per mile)	Proposed Survey (cost per mile)
Preliminary Office Study	-	\$ 75 ¹
Field Boring and Sampling	\$ 850	\$ 590
Laboratory Testing	\$ 620	\$ 365
Preparation of Report	\$ 575	\$ 575
TOTAL	\$ 2,045	\$ 1,605
ESTIMATED SAVINGS/MILE		\$ 440
PERCENTAGE REDUCTION IN COST		22%

TABLE 13
COSTS OF ORIGINAL AND PROPOSED
SUBSURFACE INVESTIGATION PROGRAMS
CASE STUDY 3

¹
40 hours at \$15 per hour. for eight miles.

1. Extensive boring and sampling is required in cut areas in rolling topography to insure adequate identification of materials to be used in embankment construction.
2. The materials are of an origin-texture combination that inherently requires comparatively many laboratory tests to adequately predict their characteristics.

PLATE 3

CASE STUDY 4
INTERSTATE ROUTE 70
HENRY COUNTY

Geology

The study area is characteristically a monotonously flat upland plain cut by a wide trough-like valley, 40 to 60 feet in depth. The upland plains were formed by the deposition of drift during both the Illinoian and Wisconsin glacial stages. Meltwaters of the receding ice sheet cut a sluiceway in a preglacial valley, and deposited materials consisting largely of stratified sands, silts, and gravels. In recent times, a thin layer of silt of eolian origin has been deposited on the upland soils, and flood plains and peat deposits have formed in the sluiceway. Remnants of the Champaign morainic system are mapped in the study area, but these have little topographic expression and are believed to be similar in texture to the ground moraine of the area (15). The unconsolidated deposits of the area are underlain by bedrock at a depth which varies from less than 150 to more than 250 feet. The bedrock formations are of Silurian Age and dip to the west away from the Cincinnati Arch (35). A surficial geology map, Figure 22, and a geologic columnar section, Table 14, are presented on the following pages. Descriptions of the significant units are presented in the following paragraphs.

After Wayne (55)

SURFICIAL GEOLOGY MAP

CASE STUDY 4

LEGEND

Valley Train and Outwash
Plain Sediments

End Moraine (Mostly Till;
Includes Small Areas of Ice
Contact Drift)

Ground Moraine (Mostly
Till)

FIGURE 22

System	Series	Stage	Formation	Description
Quaternary	Pleistocene	Recent	Unnamed	Lower flood plain and organic deposits
			Atherton	Valley train deposits
		Wisconsin	Trafalgar	Clayey glacial moraine deposits
		Illinoian	Jessup	Fine textured glacial drift
Silurian			Unnamed	Massive limestone and dolomite

TABLE 14
GENERAL GEOLOGIC COLUMNAR SECTION
CASE STUDY 4

Lower Flood Plain Deposits (Quaternary). These deposits consist of silts, sands, and fine gravels with occasional areas of muck and peat in depressed topographic positions. They are generally subjected to periodic flooding (56).

Atherton Formation (Quaternary). The outwash facies of the Atherton formation consists of stratified coarse grained sediments (gravel and sand) which were deposited as valley fill by glacial meltwaters (56).

Trafalgar Formation (Quaternary). This formation is composed primarily of calcareous conglomeratic mudstone, a compact but

uncemented sandy, silty matrix that contains fairly abundant pebbles and cobbles (56). Scattered lenses of sand, silt, and gravel are included in the formation. Much of it was deposited by glacial ice and thus is till, but a minor amount has been reworked through solifluction. Lithologic variation is not significant, but different members of the formation can be distinguished. The Cartersburg Till Member has been mapped in this area (56). (See Figure 1, page 11.) Soils of the Miami Catena have formed at the surface of this member.

Jessup Formation (Quaternary). This formation consists essentially of several beds of calcareous conglomeratic mudstone and intercalated lenses of clay, silt, gravel, marl and peat. The formation is extremely variable in thickness, but is believed to underlie the Trafalgar formation by at least 40 to 50 feet (56).

Silurian Rocks (Silurian). Underlying the unconsolidated deposits in the study area are sedimentary rocks of Silurian Age. These consist essentially of massive beds of limestone and dolomite, probably of the Niagaran Series (15).

Pedology

No agricultural soil survey report was available for Henry County. There was however a report available for Wayne County which borders the study area on the east. Information from the geologic study indicated that the unconsolidated materials in both Wayne and Henry Counties were of a unique geologic origin, hence time, as a soil formation factor was considered constant. The climate was also assumed constant because of the proximity of the two counties. The agricultural soil map of Indiana (1) indicated that the soils in both counties had formed under forest

vegetation. If the soil forming factors of climate, time, and living matter were constant, the same soil series should have been formed in the areas of similar parent material and topography. On this basis, the soil survey report of Wayne County was used to identify agricultural soil series of Henry County.

The general soil associations derived on the basis of the above considerations are listed below; these associations are shown diagrammatically in Figure 23.

1. Upland Plains	(Ground Moraine)	Miami-Crosby-Brookston
2. River Terrace		Rodman-Fox-Abington
3. Flood Plain		Genesee-Eel

The agricultural soil survey report for Wayne County indicated that extensive peat deposits might be present in the narrow flood plains within the glacial sluiceways.

Typical pedological profiles for the expected soil types are presented on pages 123 and 124. Surficial textures have been inferred on the basis of airphoto interpretation. Assumed classification for horizons of Crosby and Brookston soils are made on the basis of extensive data (20). Other classifications are made on the basis of limited test and correlation data.

Airphoto Interpretation

A portion of the study area (Stations 205 to 403) is shown in an airphoto strip map, Figure 24. It was considered unnecessary to include the entire strip map here, since photo patterns of the excluded areas are similar in all respects to those shown in Figure 24. An

Association

<u>Miami, Crosby</u>	— Well to somewhat poorly drained moderately sloping upland soils
<u>Fox, Abington</u>	— Well drained nearly level terrace soils
<u>Genesee, Eel</u>	— Well drained river bottoms

FIGURE 23. SOIL ASSOCIATIONS OF THE FLAT ROCK RIVER AREA.

Miami Silt Loam

Dark grayish brown silt loam.

Yellowish brown or brown silt loam to light silty clay loam. Yellowish brown to dark brown silty clay loam to clay loam.

Light yellowish brown loam, silt loam or light clay loam till.

Topography - nearly level to strongly sloping areas on moraines and till plains. Drainage and Permeability - well drained, runoff is medium on the milder slopes and rapid on steeper slopes. Permeability is moderate.

Parent Material - calcareous glacial till of Wisconsin Age.

Crosby Silt Loam

Dark grayish brown to brown silt loam.

Yellowish brown silty clay loam or clay loam (mottled with grayish brown).

Yellowish brown to mottled grayish brown silt loam or light clay loam.

Topography - nearly level to gently undulating areas on till plains.

Drainage and Permeability - imperfectly drained, runoff is slow. Permeability is slow.

Parent Material - developed in high calcareous glacial till of Wisconsin age. Loess capping less than 18 ins. Clay content less than 28%.

Brookston Silt Loam

Very dark grayish brown silty clay loam.

Dark brown or dark yellowish brown clay loam or silty clay loam. Dark yellowish brown clay loam or silty clay loam (mottled with gray and brown).

Yellowish brown loam, silt loam or light clay loam till.

Topography - nearly level to depressed areas in till plains and moraine areas.

Drainage and Permeability - Poorly to very poorly drained. Runoff is very slow to ponded. Permeability is slow.

Parent Material - calcareous loam, silt loam, or light clay loam till of Wisconsin Age.

Fox Silt Loam

Topography - dominantly nearly level to sloping areas on outwash plains and terraces.

Drainage and Permeability - well drained, runoff is slow to very slow. Permeability is moderate.

Parent Material - silty or loamy outwash material, underlain by stratified calcareous gravel and sand.

Abington Silty Clay Loam

Topography - depressed flats in glaciofluvial outwash plains and terraces.

Drainage and Permeability - very poorly drained, internal drainage slow due to high water table.

Parent Material - highly calcareous stratified sands and gravels.

Genesee Silt Loam

Topography - nearly level areas in streams and river bottoms.

Drainage and Permeability - well drained, runoff is slow; permeability is moderate. Areas are subject to flooding.

Parent Material - alluvium derived principally from calcareous glacial drift of Wisconsin Age.

LAND FORMS AND ENGINEERING SOIL AREAS

① ALLUVIAL DEPOSITS	③ RIVER FLOOD PLAIN
② RIVER TERRACE	④ WISCONSIN GROUND MORaine

FIGURE 24
UNCONTROLLED AIRPHOTO MOSAIC
PROPOSED INTERSTATE ROUTE 70

0 1000' 5000'
SCALE

over-all examination of the area revealed two distinct photo patterns. Over most of the area, photo tones are mottled, drainage is coarse dendritic, and topography is monotonously flat. A wide trough-like river valley cuts across the area in a north to south direction. Photo tones in this valley are over-all light, although a few faint mottles are visible. Drainage patterns are absent. The landforms peculiar to these patterns and their station limits are described below.

Wisconsin Ground Moraine (Stations 100 to 268, 308 to 464).¹

Between these station limits the topography is over-all flat to gently undulating, photo tones mottled. Drainage, where developed, is coarse dendritic. Land use is intensive, entirely in farming. Keys indicate the area to be occupied by ground moraine of Wisconsin Age with associated Miami-Brookston soil series. Light photo tones indicate the surficial soils and indeed the matrix of the till is predominantly silt or silty clay texture. Inferred AASHO classification of surficial materials is A-6 or A-7.

River Terrace (Stations 268 to 294). Between these station limits the topography is over-all flat, drainage patterns are generally absent, and photo tones are light. A few faint gray mottles are visible in slightly depressed areas. Land use is generally intensive farming, although many large gravel pits are located on the terrace face. Surficial materials are fine textured, probably silts deposited by wind and water. These overlie granular materials.

Flood Plain (Stations 294 to 308). This area is occupied by the flood plain of the Flat Rock River. Old stream channels and meander

¹
Excluding Stations (192 to 198) and (344 to 348).

scars are visible. Tones are over-all dark which indicate the presence of a high water table and/or the presence of clayey surficial materials. Land use is intensive in the area, suggesting that flooding is relatively infrequent. Organic deposits may be expected in depressed locations.

Stream Valleys (Stations 192 to 198, 344 to 348). Between these station limits, alluvial deposits, consisting of stratified sands, silts, and clays washed from upland positions may be expected. The gullies and small stream valleys in which these materials have been deposited are generally saucer-shaped, and stream gradients are flat.

Engineering Problems

The major engineering problems anticipated in the study area are those associated with the Miami-Crosby-Brookston catena. The high plasticity of the B-horizon of these soils makes drainage and subgrade support in minor cut and transition areas problematical. However, these soils usually provide adequate support for embankment sections. Proper moisture control will aid in adequate compaction of these materials in subgrade and in embankment sections. Organic topsoil may be present to a depth of one foot or more in areas of depressed topographic position.

Occasional peat deposits may be found within the flood plain of Flat Rock River. The alluvial soils within the stream valleys are subject to periodic flooding and may cause construction problems.

Design Considerations

The proposed section of Interstate Route 70 crosses Henry County near its southern border and follows a general east-west direction. The route is to be constructed almost entirely in fill, with few cut areas. The proposed centerline profile and existing topographic conditions are shown in Plate 4. A high embankment is proposed over the Nickel Plate Railroad between Stations 108 and 140. The foundation materials between these station limits are considered adequate from the standpoint of stability and settlement, and the site investigation should be of a relatively modest nature. The cuts proposed in the upland areas adjacent to the Flat Rock River sluiceway should not require extensive investigation. A ten-inch reinforced concrete pavement is proposed for the facility.

Predictions Based on Preliminary Studies

The findings of the photo-geological and pedologic studies are summarized and tabulated in Plate 4. Borders were delineated on the basis of stereoscopic examination of aerial photographs and closely followed the major topographic changes. These borders are in general agreement with those shown on the geologic map, Figure 22. Specific observations within each of the delineated landforms are discussed in the following paragraphs. Material from cut areas should be generally acceptable for use in subgrade and embankment construction. Some handling problems may occur due to the plasticity of the B-horizon. The C-horizon or parent material in the upland areas (ground moraine) should exhibit uniform characteristics throughout.

The most variable deposits will be those on the flood plain and in the stream valleys. Explorations should be more intensive here.

Wisconsin Ground Moraine (Stations 100 to 268, 308 to 464).¹ The geologic and airphoto study indicated that the pedologic soils between these station limits would probably belong to the Miami-Crosby-Brookston catena. Because this catena is one of the most prevalent in Indiana, the classification and engineering properties of several hundred samples of soil types from this catena have been determined. Statistical and other analyses have been applied to data from the laboratory tests, and the results of these analyses are generally available (20), (60). Using these results, the writer assigned the classification to the horizons and parent material as shown in Plate 4. Bedrock was not expected to be encountered in any of the borings.

River Terrace (Stations 268 to 294). The predicted sequence of materials within the above station limits is shown in Plate 4. There was no definite indication in any of the preliminary studies of the depth of silty material which covers the more granular soils on the terrace positions. These granular materials are probably at relatively great depth (10 to 15 feet). This was inferred from the airphoto study of the area, which showed standing water in the pit areas, indicating that granular materials are probably being excavated below the ground water table.

Flood Plain (Stations 294 to 308). All of the preliminary studies indicated that the most variable deposits will be those on the river flood plain and within the small stream valleys.

¹
Excluding Stations (192 to 198) and (344 to 348).

Proposed Subsurface Investigation

In general the field survey and laboratory testing of soils for this case study were planned to emphasize the definition of:

1. The relative uniformity of the soils in the Wisconsin ground moraine areas.
2. The areal extent of the flood plain and stream valley areas, and the variability of the soil profile within these areas.
3. The depth and variability of the silty soils on the terrace positions.

Spacing and Depth of Borings

Because of the expected soil profile uniformity (both areally and with depth), borings for embankments in the Wisconsin ground moraine areas were spaced at 1,000-foot intervals and located alternately right and left on the proposed roadway centerlines. These borings were generally located in areas of depressed topographic position, such positions having been considered most significant from a sampling standpoint. In cut areas within the ground moraine, the spacing was decreased to 300 feet, with borings usually located alternately to the left and right on the proposed roadway centerlines. Borings were located to adequately sample and classify all material to be excavated and placed in embankments. In transition areas (cut to fill), borings were located to define the clayey B-horizon both areally and with depth.

On terrace positions, borings were spaced at 500-foot intervals and were located generally in depressed topographic positions.

Spacings on the flood plain were decreased to a maximum of 300 feet and were located so as to define the limits of the variable alluvial deposits. At least one boring was proposed to be carried into the underlying parent material (Wisconsin ground moraine).

Laboratory Tests

Hampton (20) has shown that results from 9 to 14 classification tests are required to define a statistical average of the classification values of the till material. In the proposed investigation these tests were concentrated in cut areas. The river terrace deposits are expected to be generally uniform and few tests were proposed. In the flood plain and other alluvial areas where soils are expected to be variable, visual classification was proposed, although samples of extreme soil types were to be obtained for classification purposes.

Compaction and CBR tests were proposed for each soil type exposed in cut areas.

Because of the relatively slow permeability of the soils, samples may have relatively high moisture contents when sampled. For this reason, allowance is made in the proposed program for natural moisture content determinations on all samples.

The number, average spacing, and average depth of borings in each of the landform units are itemized in Table 15. Also tabulated are the estimated number and type of laboratory tests for the proposed subsurface investigation program.

Original Subsurface Investigation Report

One subsurface investigation report was available which included the study area within its scope. Unlike the surveys of Case Study 3,

<u>Item</u>	<u>Topographic or Landform Unit</u>		
	<u>Wisconsin Ground Moraine</u>	<u>River Terrace</u>	<u>Flood Plain</u>
Total Number of Borings	56	5	4
Number of Borings Per Mile	9	10	15
Average Spacing of Borings (feet)	600	500	350
Type of Boring	Auger	Auger	Auger
Total Number of Classification Tests	10	5	5
Total Number of Compaction Tests	8	-	-
Total Number of CBR Tests	4	-	-
Total Number of Natural Moisture Contents	10	5	5

TABLE 15
SUMMARY OF PROPOSED SUBSURFACE INVESTIGATION PROGRAM
CASE STUDY 4

the field survey upon which this report was based was conducted according to the "Requirements for Roadway Soil Survey" outlined in Case Study 1. Either hand or power auger borings were made at specified intervals of 300 feet alternating along the respective pavement centerlines, the only exceptions being between Stations 290 and 295 where recent deep excavations for gravel pits exposed the materials for visual classification.

In accordance with the procedure established in the requirements, at least one disturbed sample was taken for each general type of soil encountered per mile of line investigated. More than 30 such samples were taken in locations considered representative of all conditions encountered. Inasmuch as no special problem areas were encountered in the survey, it was probably not necessary to take special samples at any locations.

The subsurface investigation report contains a detailed field log of each boring, a tabulation of laboratory test results, and a discussion of the findings of the survey together with recommendations relative to design and construction problems.

The total number, number per mile, and average spacing of borings for each of the landform units are itemized in Table 16. Also tabulated are the number and type of laboratory tests within each unit.

Comparison of Original and Proposed Subsurface Investigation Program

As in the previous case studies, the original and proposed programs were compared on the bases of extent, results, and costs.

<u>Item</u>	<u>Topographic or Landform Unit</u>			
	<u>Wisconsin Ground Moraine</u>	<u>River Terrace</u>	<u>Flood Plain</u>	
Total Number of Borings	118	7	4	
Number of Borings Per Mile	19	14	15	
Average Spacing of Borings (feet)	275	375	350	
Type of Borings	Auger	Auger	Auger	
Total Number of Classification Tests	25	-	-	
Total Number of Compaction Tests	9	-	-	
Total Number of CBR Tests	2	-	-	
Total Number of Natural Moisture Contents	28	-	-	

TABLE 16
SUMMARY OF ORIGINAL SUBSURFACE INVESTIGATION PROGRAM
CASE STUDY 4

Tables 15 and 16 show the extent of the two programs. In the original program, the average boring interval on the river terrace is greater than in the other units only because the profile could be examined in open cuts. Otherwise, the interval would be nearly equal in all units. In the proposed program, the greatly increased boring interval in the moraine and terrace positions reflect the general uniformity expected. The interval is decreased in the flood plain area, reflecting the expected variability. Even though the interval in the moraine area is nearly doubled, 56 profiles are sampled. Fewer classification tests are recommended in the proposed program, and they are distributed throughout the study area. The number of compaction tests in each program is nearly similar, while two more CBR tests are recommended in the proposed program.

"Typical" field logs for each topographic unit are shown in Figures 25 and 26. These may be compared with the inferred sequence and classification of materials shown in Plate 4. The materials are generally as predicted with exceptions as noted below. The moraine deposits west of the Flat Rock River are more granular than predicted, and the comparison of texture and color differences between profiles east and west of the river suggest that the deposit west of the river is actually the terminal moraine of the Champlain Moraine System shown on the geologic map, Figure 22. (Terminal or ridge moraine is characteristically more granular than ground moraine.) The alluvial deposits within the flood plain of the Flat Rock River do not exhibit the variability expected. Instead, the profile is remarkably uniform, consisting of 6 to 12 inches of topsoil over uniform A-4 material to

Ground Moraine
(Upland Plains)

Terrace Deposits

Sta. 118+00

Sta. 321+00

Sta. 286+00

TYPICAL FIELD BORING LOGS, CASE STUDY 4
FIGURE 25

Alluvial Deposits

Flat Rock River Flood Plain

Sta. 303 00

Topsoil

Brown sandy clay loam
A-4 (1)

Small Stream Deposits

Sta. 345 00

Dark brown topsoil
(wet)

Brown clay A-6 (6)

Gray sandy loam
A-2-4 (0)

TYPICAL FIELD BORING LOGS, CASE STUDY 4
FIGURE 26

the depths sampled. Alluvial deposits within the smaller stream valleys display the variability expected. To determine the degree of uniformity demonstrated by the plasticity characteristics of the till, the results of 19 classification tests were plotted on the plasticity chart shown in Figure 27. As was the case in other deposits of unique geologic origin, the C-horizon or parent material did demonstrate good uniformity.

The costs of the original and proposed surveys are given in Table 17. These costs generally reflect the extent of the survey as previously discussed. Because of fewer borings, anticipated field boring and sampling costs are lower in the proposed program. Because of a higher number of compaction and CBR tests, laboratory testing costs are slightly higher in the proposed program. As in all other case studies, a net saving is anticipated.

Summary

The geologic literature was of great value in defining the origin of the unconsolidated materials in the area. This study indicated that the major portion of the area was covered with glacial till of unique origin.

The airphoto study confirmed the uniformity of glacial material, and was of greatest value in delineating the contrasting parent material boundaries (terrace, flood plain, and alluvial deposits).

Although no soil survey report was available for the area in question, it was possible to infer soil series for the study area from agricultural soil maps available for an adjacent and similar area, and from the extensive correlation data available for these series to

PLASTICITY CHARACTERISTICS OF
THE MIAMI CROSBY BROOKSTON CATENA
FIGURE 27

<u>Item</u>	<u>Original Survey</u> <u>(cost per mile)</u>	<u>Proposed Survey</u> <u>(cost per mile)</u>
Preliminary Office Study	-	\$ 50 ¹
Field Boring and Sampling	\$ 555	\$ 335
Laboratory Testing	\$ 175	\$ 205
Preparation of Report	\$ <u>575</u>	\$ <u>575</u>
TOTAL	\$ 1,305	\$ 1,165
ESTIMATED SAVINGS/MILE		\$ 240
PERCENTAGE REDUCTION IN COST		18%

TABLE 17
COSTS OF ORIGINAL AND PROPOSED
SUBSURFACE INVESTIGATION PROGRAMS
CASE STUDY 4

¹
20 hours at \$15 per hour for six miles.

predict the AASHTO classification of the unconsolidated materials. The geologic and airphoto studies indicated that such a procedure was feasible.

Because of the over-all flat topography, the general uniformity of the materials, and the few parent material borders to be defined, little field boring and sampling was required. Material textures were such that only moderate laboratory testing was anticipated. Resulting exploration costs were low.

PLATE 4

TE 70

PROFILE — INTERSTATE ROUTE 70

HENRY COUNTY

SUMMARY ANALYSIS OF PROCEDURES AND COSTS

Subsurface Investigation Procedures

In all the case studies, information obtained from the proposed investigation (planned on the basis of a modest office study) was at least as adequate as the extant investigation for the design and construction of the proposed facility (excluding in the comparison those areas considered to be special "sites" because of potential foundation difficulties). Because of the contrasting geology, topography and parent material types in each of the study areas and the amount and type of source information available for these areas, the benefit derived from the "tools" of geology, pedology, and airphoto interpretation was not equal in all instances. In addition, no single source was considered adequate in any one of the case studies.

On the basis of these studies the relative value of each of the tools employed can be postulated. In particular, geologic investigations are most applicable:

1. Where unconsolidated materials are relatively shallow, hence knowledge of the nature and attitude of the underlying bedrock is essential for proper design and construction;
2. Where the information listed above cannot be determined accurately from any other source (for example, airphoto interpretation); and

3. Where accurate large-scale surficial geology maps are available for the particular study area.

Airphoto interpretation is especially useful:

1. Where land form and parent material types are of a contrasting nature such that accurate borders may be delineated;
2. In indicating the relative uniformity of materials over a large area;
3. Where accurate large-scale surficial geology maps are not available for a study area; and
4. In indicating the drainage and erosional characteristics of an area.

Pedologic studies are of major importance:

1. In delineating soil profile and parent material borders where reliable agricultural soil survey reports and maps are available;
2. In inferring the AASHO classification of the soil horizons only where correlation data are available;
3. In indicating the general drainage and erosional characteristics of an area; and
4. In realizing a range of identifying characteristics for a particular agricultural soil series.

Where agricultural soil survey reports and maps are not available, it is possible to infer pedologic soil types based on findings of the airphoto interpretation study, with possible help from the geologic information. The accuracy of the inferences depend upon the quality of the material available from these related fields.

In general, none of the above methods offered accurate information concerning the depth to bedrock in an area. Geophysical methods (not currently employed) could contribute to this definition, particularly in the early stages of the exploration.

From the limited data available, it is difficult to determine whether or not moderate preliminary planning in the form of office studies will always result in lower exploration costs (as was the case in the studies included in this thesis). However, information obtained from field explorations so planned should be of equal or even greater value in the proper design and construction of the proposed facility.

Costs of Subsurface Investigation Programs

The cost of a subsurface investigation program depends to a large extent on the number, type, and depth of borings and samples, and to a lesser extent on the amount and kind of laboratory testing. In reviewing the costs of proposed investigations for the case studies discussed in this thesis, the writer has attempted to isolate factors which, it is believed, significantly affect the cost of an exploration program for primary highway design and construction. These factors, the geology and topography of an area, and the general texture of the parent materials, are itemized for the study areas in Table 18.

Where the geologic history of an area (especially in terms of deposition and erosion) is complex, many parent material types can be expected. If the nature of these parent materials is such that an accurate areal definition of each is necessary, field boring and sampling costs will be high. Where the topography is rolling, extensive cut areas will be required to maintain the low grades

Item	Case Study 1 Int. Route 64	Case Study 2 Int. Route 65	Case Study 3 Int. Route 69	Case Study 4 Int. Route 70
Geologic History	Complex	Simple	Slightly Complex	Simple
Topography	Rolling	Flat	Undulating to Rolling	Flat
General Texture of Parent Material	Fine Textured (A-6, A-7)	Granular (A-3, A-2)	Fine Textured (A-6, A-7)	Fine Textured (A-4, A-6)
Cubic Yards of Cut Per Mile of Project	174,834	36,632	101,265	55,478
Cost of Original Investigation per Mile	\$2,830	\$1,345	\$2,045	\$1,305
PROPOSED INVESTIGATION COSTS PER MILE				
Field Borings and Sampling	\$1,055	\$ 315	\$ 590	\$ 335
Testing	765	130	365	205
Preliminary Study	150	100	75	50
Preparation of Report	575	575	575	575
TOTAL	\$2,545	\$1,120	\$1,564	\$1,165
PERCENTAGE REDUCTION IN COST	10%	17%	22%	18%

TABLE 18
COMPARISON OF COSTS OF INVESTIGATION
PROGRAMS FOR CASE STUDIES

required for primary highways, as well as to approximately balance the earthwork quantities. If the materials from these cuts are expected to be variable, and if said excavated material is to be used for embankment construction, many borings and samples will be required to examine and classify the materials, and many laboratory tests may be required to adequately define their compaction and load deformation characteristics. Conversely, where the geologic history is simple and the topography is flat, minimal field boring and sampling would be required.

Further, it is postulated that where the geology, topography, and general texture of the parent material of areas are similar, subsurface investigation costs should also be similar (given the same facility type with the same design standards). Since the features of (1) land relief, (2) structure, type and origin of bedrock, and (3) sequence of geologic events responsible for the type and characteristics of soil materials are similar throughout a physiographic region, subsurface investigation costs throughout the region (barring local peculiarities) should be similar. Therefore, it should be possible to regionalize exploration costs on the basis of physiographic units. (See Figure 2.) Such a regionalization of costs is attempted in Table 19. Only exploration costs for the Wabash Lowland, Tipton Till Plain, and Kankakee Lacustrine Section of the Northern Moraine and Lake Region were obtained directly from the case studies. For most other physiographic units of Indiana it was possible to infer costs by comparing the geology, topography, and general parent material textures of the units with the geology, topography, general parent material textures,

Physiographic Section ¹	Topography	Geology	Parent Materials	Estimated Cost per Mile
Calumet Lacustrine Section	Ridge and swale	Wisconsin glacial deposits (reworked)	Alluvial and eolian deposits (sand); lacustrine clays and sands.	\$1,200
Valparaiso Moraine Section	Knoll and sag	Wisconsin glacial deposits	Silty-clay till	\$1,500
Kankakee Lacustrine Section				
a. Kankakee Marsh	Flat - some dune ridges	Wisconsin glacial deposits	Sand and gravel outwash plains - some peat areas	\$1,000
b. Iroquois Lacustrine Plain	Flat	Wisconsin glacial deposits	Silty and clayey lacustrine deposits	\$1,200
c. Marseilles Moraine	Hummocky topography	Wisconsin glacial deposits	Silty clay glacial till	\$1,500

TABLE 19
REGIONALIZED SUBSURFACE INVESTIGATION COSTS

¹ See Figure 2, page 24.

Physiographic Section	Topography	Geology	Parent Materials	Estimated Cost Per Mile
Scottsburg Lowland	Broad flat valleys, notable lack of steep hills	Illinoian and Wisconsin glacial deposits	Alluvium and glacial drift over bedrock	(Not possible to infer cost from data available)
Norman Upland	Rugged	Mississippian SS and SH - Illinoian and Wisconsin glacial deposits	Residual soils from interbedded LS, SS, and SH - alluvium - glacial drift	(Not possible to infer cost from data available)
Mitchell Plain	Karst topography (Sinkholes)	Harrodsburg LS - Illinoian glacial deposits	Residual LS soil - glacial drift	(Not possible to infer cost from data available)
Crawford Upland	Rugged - uneven	Mississippian LS, SS, and SH - Illinoian glacial deposits	Residual soils from interbedded LS, SS, SH - glacial drift	(Not possible to infer cost from data available)
Wabash Lowland	Rolling to flat in lacustrine areas	Illinoian and Wisconsin glacial deposits - Cosnaugh SS and SH	Lacustrine clays and silts - loess - outwash sands and gravels - glacial drift - Residual soils from interbedded SS and SH	\$1,500 ¹ to \$2,500

TABLE 19
(continued)¹ Depending on topography and depth of loess cover.

Physiographic Section	Topography	Geology	Parent Materials	Estimated Cost Per Mile
Steuben Moranal Lake Section	Undulating to rolling - crested in areas of ridge moraine	Wisconsin glacial deposits	Outwash sands and gravels. Granular and fine textured glacial drift	\$1,000 - \$1,500
Maumee Lacustrine Section	Flat	Wisconsin glacial deposits	Lacustrine clays	\$1,200
Tipton Till Plain	Undulating to softly rolling	Wisconsin glacial deposits	Fine textured glacial till. Granular ridge moraine (locally eskers kames; valley train and outwash deposits)	\$1,200
Dearborn Upland	Rugged - local relief in 100's of feet	Illinoian glacial deposits. Ordovician SH	Fine textured glacial till; granular outwash deposits; soils from interbedded LS and SH	(Not possible to infer cost from data available)
Muscatatuck Regional Slope	Regionally gently sloping to flat - deeply dissected (200' in stream valley)	Illinoian glacial deposits	Fine textured glacial drift; valley train and outwash deposits	(Not possible to infer cost from data available)

TABLE 19
(concluded)

and costs of the case studies. However, in some units the diagnostic elements listed above were not sufficiently similar to infer costs. Where no cost can be inferred it is noted in the table.

SUMMARY

1. The hypothesis of this study was that consultation of geologic and pedologic data, and the examination of airphoto coverage in an office study phase, preliminary to a physical subsurface investigation for highway design and construction purposes, has economic justification. It was believed that a modest application of these aids or "tools" would prove desirable because with them:

- (a) the total cost of the investigation could be reduced, or
- (b) the information gained from the investigation would more adequately characterize the subsurface conditions.

2. In an attempt to render the study both practical and quantitative, the case study approach was utilized. With the assistance of the office of the state soils engineer, four projects along the Indiana Interstate System were selected for intensive study. The criteria for selection were:

- (a) each project should be generally representative of sizeable parts of the state,
- (b) enough geologic, pedologic, and airphoto coverage should be available to permit an effective office study, and
- (c) each project should have been "bored out" and the subsurface investigation report completed so that a comparison between the extant and the proposed investigations could be accomplished.

3. To render the cost comparisons between original and proposed investigations most useful (for the study objective), certain factors were held constant between said investigations. In general these were:

- (a) the methods of penetrating the subsurface and extracting samples,
- (b) the kinds of samples extracted, and
- (c) the types of laboratory tests to be considered.

4. It was believed that the special problems posed by deep cuts and/or high fills should be separated from the ordinary or roughly "at-grade" situations, and in the few instances that these were encountered in the study, they were classed as special "sites" and excluded from further consideration.

5. Reasonably available geologic and pedologic maps, reports, as well as airphoto coverage were assembled, major soil areas were interpreted and bounded, and soil profiles for these areas were inferred. The proposed subsurface investigation was then formulated in detail, based upon the office study.

6. Reference to the subsurface investigation reports of the extant or original investigations, plus cost data supplied by the State, permitted the two investigations to be compared for each case. The cost of the office study was of course included in the total cost of the proposed investigation.

7. The costs of proposed investigations were related to the geologic and topographic conditions for which they obtained (Table 18). Regionalization of subsurface investigation costs, using physiographic subdivisions in Indiana, was attempted (Table 19).

CONCLUSIONS

As a result of the four case studies undertaken with respect to portions of the Indiana Interstate Highway System, the following conclusions are drawn.

1. Readily accessible literature from the sciences of geology, and pedology and simple applications of the technique of airphoto interpretation can be used to advantage in planning (and probably in interpreting) physical subsurface investigation programs.
2. The cost of exercising an office survey phase (for examination of geologic, pedologic, and airphoto coverage) is offset by the reduction in cost of the physical subsurface investigation which results from such planning. This saving is accomplished with no apparent loss in characterization of the subsurface materials.
3. The relative value of the geologic, pedologic, and airphoto interpretation "tools" varies with the geographic location. In general, best results are obtained when all three are used in a complementary fashion.
4. The cost of subsurface investigation appears to be influenced to an important degree by the factors of: (See Table 18.)

- (a) the geologic origin and complexity of parent materials,
- (b) the topography of the study area, and
- (c) the general texture of the parent materials.

5. It may be possible to regionalize subsurface investigation costs on the basis of physiographic units. (See Table 19.)

RECOMMENDATIONS

1. An expansion of this study to other cases is justified. The new research should:
 - (a) be referenced to the latest revision of subsurface investigation requirements as applied to primary Indiana highways, and
 - (b) require that the office survey be undertaken in complete isolation from the information that had or would later be revealed by the physical exploration.
2. Subsurface investigation procedures for sites of major engineering activity (deep cuts and high fills) should be re-examined in view of the potential contribution to net economy of
 - (a) office studies, and
 - (b) recent developments in analysis and definition and interpretation of soil resistance.

THE BUREAU

1. "Index of Public Buildings", Department of Housing, Public Buildings, (No. 100)
2. "Report of Investigation of Public Buildings", Department of Housing, (No. 100)
3. "Report of Investigation of Public Buildings", Department of Housing, (No. 100)
4. "Report of Investigation of Public Buildings", Department of Housing, (No. 100)
5. "Report of Investigation of Public Buildings", Department of Housing, (No. 100)
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4. "Report of Investigation of Public Buildings", Department of Housing, (No. 100)
5. "Report of Investigation of Public Buildings", Department of Housing, (No. 100)
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APPENDIX A

INDIAN ARTS AND CRAFTS IN THE STATE OF INDIANA

The reports and maps listed on the following pages, arranged in
chronological order, are publications of the Indiana Department of Conserva-
tion, Geological Survey, and may be purchased from the Publications
Section, Geological Survey, Indiana Department of Conservation, Indiana.
Many out-of-print publications (owned by an individual) are
particularly relevant to the subject of indigenous occupations, and
are included in the list. **APPENDIX A** contains a list of the
publications of the Geological Survey and its predecessor, the Indiana
Geological Survey.

Publications

- No. 1. Fisher, G. M., "Petrography of the Lower Mahan Valley",
1900.
No. 2. Thompson, W. D., "Stratigraphic and Geologic Maps of
Indiana", 1901.
No. 3. Thompson, W. D., and Thompson, W. D., "Stratigraphic and Geologic
Maps of Indiana", 1901.

Referred for this section was extracted in part from "List of
Geologic Publications of Indiana", Indiana Department of Conservation,
Geological Survey, 1901, 1903.

APPENDIX A

GEOLOGIC REPORTS AND MAPS HIGHLY RELEVANT
TO SUBSURFACE EXPLORATIONS IN INDIANA¹

The reports and maps listed on the following pages, except as otherwise noted, are publications of the Indiana Department of Conservation, Geological Survey, and may be purchased from the Publications Section, Geological Survey, Indiana University, Bloomington, Indiana. Where out-of-print publications (denoted by an asterisk) are particularly relevant to the subject of subsurface explorations, they are included in the list. These publications may be consulted in the offices of the Geological Survey and in many public and technical libraries.

Bulletins

- No. 2 Fidler, M. M., "Physiography of the Lower Wabash Valley", 1948.
- No. 4 Thornbury, W. D., "Glacial Sluiceways and Lacustrine Plains of Southern Indiana", 1950.
- No. 5* Wayne, W. J., and Thornbury, W. D., "Glacial Geology of Wabash County, Indiana", 1951.

¹

Material for this section was extracted in part from "List of Geologic Publications of Indiana", Indiana Department of Conservation, Geological Survey, Oct., 1963.

- No. 6 Weir, C. E., "Geology and Mineral Deposits of the Jasonville Quadrangle, Indiana", 1952.
- No. 7 Bieber, C. L., and Smith, N. M., "Industrial Sands of the Indiana Dunes", 1952.
- No. 20 Gray, H. H., Jenkins, R. D., and Weidman, R. M., "Geology of Huron Area, South-Central Indiana", 1960.
- No. 21 Wayne, W. J., "Stratigraphy of the Ohio River Formation", 1960.
- No. 24 Nevers, G. M., and Walker, R. D., "Annotated Bibliography of Indiana Geology through 1955", 1962.
- No. 25 Wayne, W. J., "Pleistocene Formations in Indiana", 1963.

Circulars

- No. 1 Deiss, C. F., "Geologic Formations on which and with which Indiana's Roads are Built", 1952.

Directories

- No. 6 McGregor, D. J., "Directory of Sand and Gravel Producers in Indiana", 1958.

Reports of Progress

- No. 7 Wayne, W. J., "Thickness of Drift and Bedrock Physiography of Indiana North of the Wisconsin Glacial Boundary", 1956.
- No. 17 McGregor, D. J., "Gravels of Indiana", 1960.
- No. 26 Gray, H. H., "Outcrop Features of the Mansfield Formation in Southwestern Indiana", 1962.

Special Reports

- No. 2 Gray, H. H., "Geology of the Upper Patoka Drainage Basin", 1963.

Numbered Publications of the Division of Geology

- No. 21* Logan, W. N., and others, "Handbook of Indiana Geology", 1922.
- No. 108 Logan, W. N., "The Subsurface Strata of Indiana", 1931.

MAPS OF INDIANA

Atlas of Mineral Resources of Indiana Maps

- No. 9 Geologic Map of Indiana, 1956. Scale, 1:1,000,000.
- No. 10 Glacial Geology of Indiana, 1958. Scale, 1:1,000,000.

Coal Investigation Maps

- No. C 1 Geology and Coal Deposits of the Jasonville Quadrangle, Clay, Greene and Sullivan Counties, Indiana, 1950.
- No. C 9 Geology and Coal Deposits of the Linton Quadrangle, Greene and Sullivan Counties, Indiana, 1951.
- No. C11 Geology and Coal Deposits of the Dugger Quadrangle, Sullivan County, Indiana, 1954.
- No. C16 Geology and Coal Deposits of the Hymersa Quadrangle, Sullivan County, Indiana, 1954.
- No. C17 Geology and Coal Deposits of the Shelburn Quadrangle, Sullivan County, Indiana, 1954.
- No. C27 Geology and Coal Deposits of the Seelyville Quadrangle, Vigo County, Indiana, 1958.
- No. C28 Geology and Coal Deposits of the Coal City Quadrangle, Greene, Clay and Owen Counties, Indiana, 1959.
- No. C41 Geology and Coal Deposits of the Switz City Quadrangle, Greene County, Indiana, 1960.

Regional Geologic Maps

- Geologic Map of the Indianapolis 1° x 2° Quadrangle, Indiana and Illinois, 1961. Scale, 1:250,000.

United States Geological Survey Folios

- No. 67* Danville Quadrangle, 1900. Map Scale, 1:62,500.
- No. 81* Chicago Quadrangle, 1902. Map Scale, 1:62,500.
- No. 84* Ditney Quadrangle, 1902. Map Scale, 1:125,000.
- No. 105* Patoka Quadrangle, 1904. Map Scale, 1:125,000.

Index Maps

Geologic Map Index of Indiana, 1950. Scale, 1:750,000.

APPENDIX B

STATUS OF AGRICULTURAL
SOIL MAPPING IN INDIANA¹

Table B-1 lists the counties of the state of Indiana in alphabetical order. The dates in the "Year" column usually refer to the year in which the field work was completed; however, for mapping done by the Soil Conservation Service prior to 1952, the indicated year is the date the soil report was published.

The tabulation shows the rating of the soil surveys. These ratings are based on adequacy of mapping as follows:

Rating 1. Soil maps with soil names in accord with present day standards. Individual soil areas as small as 5 to 10 acres generally are shown on the maps; a soil area as small as two acres may be shown if the soil is in marked contrast to those in surrounding areas, as, for example, a small area of poorly drained soil surrounded by well-drained soils. In the tabulation this rating has been subdivided into (1a) and (1b) because of significant differences in the surveys.

Rating 1a. Recent survey; field work on aerial photographs; field mapping scale 1:20,000 (3.17 inches to one mile) or larger;

1

Material copied in part from "Status of Agricultural Soil Mapping in the United States, July, 1957", Highway Research Board Bulletin 22-R, and amended as required.

field sheets or copies available for reference; soil boundaries, including those of slope and erosion phases, well-located with respect to field boundaries and other reference points.

Rating 1b. Recent or fairly recent surveys that differ from those of Rating (1a) in one or more of the following characteristics: scale of field mapping smaller than 1:20,000; maps on photographic base not available for reference; or some supplementary information, either additional mapping separations or greater precision of boundaries, is needed for interpretation in relation to soil-use planning.

Rating 2. Older soil maps with soil names mostly in accord with recent correlations, but scale smaller or soil boundaries less precise than present day standards. Individual soil areas smaller than 10 acres may be shown on the maps. The map scale is normally one inch to one mile. Most of the maps were published after 1930.

Rating 3. Soil maps made mostly before 1930; soil boundaries somewhat generalized or soil classification not entirely in accord with present correlation, or both. Plane table was generally used in preparation of base map, but topographic maps were used in some areas. Soils valuable for crops are likely to be shown in more detail than other soils. The major soil boundaries are likely to be well-defined but individual soil areas less than 10 acres are not apt to be differentiated.

Rating 4. Rather general soil maps, with some significant boundaries accurately located. Many of the soil names are not in accord with present nomenclature. The maps show many important local differences in soils, but also fair to show some differences

because of the generalized character of the work. The maps still have some value when properly interpreted.

Rating 5. Soil maps of little value now because of incorrectly drawn boundaries or inadequate classification. The mapping was mostly done before an adequate system of soil classification and mapping had been developed.

These five ratings have been made on the basis of (a) the soil classification scheme used, (b) the scale and type of base maps, and (c) the degree of detail in the classification and mapping. In some cases the ratings may not reflect a correct evaluation of the survey information for engineering purposes, but in general, the reliability of the information increases as the rating number decreases. The engineer may need to confer with a representative of Soil Conservation Service to determine the approximate value of the soil map in specific engineering applications; such conferences may make the soil survey have greater value to the engineer than the rating indicates.

The availability of the prepared maps is indicated in the tables by the following symbols:

- L - Free supply and sales stock exhausted; copies may be consulted in the libraries shown at the end of Table B-1.
- GPO - For sale by Superintendent of Documents, Government Printing Office, Washington 25, D.C. Copies may be consulted in the libraries listed.
- IP - In progress. Field work has been completed and publication of the soil survey report is in progress.

TABLE B-1

RATING AND AVAILABILITY OF AGRICULTURAL
SOIL SURVEYS IN INDIANA

<u>County Name</u>	<u>Year</u>	<u>Rating</u>	<u>Availability</u>
Adams	1921	3	L
Allen	1908	4	L
Allen	1965	1a	IP
Bartholomew	1936	2	GPO
Benton	1916	4	L
Blackford	1928	3	L
Boone	1912	4	L
Brown	1936	2	GPO
Carroll	1940	1b	IP
Cass	1939	1b	GPO
Clark			
Clay	1922	3	GPO
Clinton	1914	3	L
Crawford			
Daviess			
Dearborn			
Decatur	1919	4	L
DeKalb			
Delaware	1913	4	L
Dubois	1930	3	GPO
Elkhart	1914	4	L
Fayette	1952	1a	IP
Floyd			-
Fountain			
Franklin	1938	2	GPO
Fulton	1937	2	GPO
Gibson	1922	3	GPO
Grant	1915	3	L
Greene	1906	5	L
Hamilton	1912	3	L
Hancock	1925	3	GPO
Harrison			
Headricks	1913	3	L
Henry			
Howard			
Huntington			

TABLE B-1
(Continued)

<u>County Name</u>	<u>Year</u>	<u>Rating</u>	<u>Availability</u>
Jackson			
Jasper			
Jay			
Jefferson			
Jennings	1932	3	GPO
Johnson	1938	2	GPO
Knox	1934	2	GPO
Kosciusko	1922	3	GPO
Lagrange			
Lake	1917	3	L
La Porte	1934	2	GPO
Lawrence	1922	3	GPO
Madison	1903	5	L
Marion	1907	5	L
Marshall	1904	5	L
Martin	1936	2	GPO
Miami	1927	3	L
Monroe	1922	3	L
Montgomery	1912	3	L
Morgan	1937	2	GPO
Newton	1941	1a	GPO
Noble	1940	1b	GPO
Ohio	1930	3	GPO
Orange			
Owen			
Parke	1949	1b	IP
Perry			
Pike	1930	3	GPO
Porter	1916	3	L
Posey	1902	5	L
Pulaski			
Putnam	1925	3	L
Randolph	1931	3	GPO
Ripley			
Rush	1930	3	GPO
St. Joseph	1938	2	GPO
Scott	1904	5	L
Shelby			
Spencer			
Starke	1915	3	L
Steuben	1933	2	GPO
Sullivan			
Switzerland	1930	3	GPO
Tippecanoe	1940	1b	GPO

TABLE B-1
(Continued)

<u>County Name</u>	<u>Year</u>	<u>Rating</u>	<u>Availability</u>
Tipton	1912	4	L
Union	1952	1a	IP
Vanderburgh	1939	1b	GPO
Vermillion	1930	3	GPO
Vigo			
Wabash			
Warren	1914	4	L
Warrick			
Washington	1932	2	GPO
Wayne	1925	3	L
Wells	1915	3	L
White	1915	4	L
Whitley			

Libraries in Indiana in which complete sets of Field Operations of the Bureau of Soils and other soil survey reports may be found:

Bloomington, Indiana University
 Crawfordsville, Wabash College
 Fort Wayne, Public Library
 Greencastle, DePauw University
 Hanover, Hanover College
 Huntington, City Free Library
 Indianapolis, Indiana State Library
 Indianapolis, Public Library
 Indianapolis, State Dept. of Geology
 Jasper, Jasper College
 Lafayette, Purdue University
 Lafayette, Agricultural Exp. Station
 LaPorte, LaPorte Public Library

Elkhart, Elkhart-Carnegie
 Public Library
 Evansville, Willard Library
 Merom, Union Christian College
 Notre Dame, Lemonier University
 of Notre Dame
 Pendleton, Carnegie Public
 Library
 Richmond, Earlham College
 Richmond, Morrison Reeves
 Library
 Terre Haute, Indiana State
 Teachers College
 Terre Haute, Emeline Fairbanks
 Memorial Library
 Valparaiso, Valparaiso U.
 French Lick, Public Library

APPENDIX C

PHOTOGRAPHS AND MAPS AND REPORTS RELATING TO THE USE OF AIRPORT PHOTOGRAPHY

Many engineering and other data reports have been prepared by the use of aerial photography for the Indian State Highway Department by the State Highway Research Project of Purdue University. The maps are available for use by the Airports Administration at Purdue University and to such extent as reports are available for consultation. Details of the data which are available are listed in Table C-1.

APPENDIX C

This appendix (see also Table C-1) contains a list of the reports and maps prepared by the Airports Administration at Purdue University and is intended to serve as a guide to the location of these reports and maps. A comprehensive bibliography of these reports and maps is included in the following pages.

For a complete description of these maps and reports, the reader is referred to the appendixes listed in the preceding pages.

APPENDIX C

ENGINEERING SOIL MAPS AND REPORTS
PREPARED BY THE USE OF AERIAL PHOTOGRAPHS¹

County engineering soil maps and reports have been prepared by the use of aerial photographs for the Indiana State Highway Department by the Joint Highway Research Project at Purdue University. The maps are generally for sale at the Airphoto Laboratory at Purdue University and, in most instances the reports are available for reference.

Counties for which these maps are available are listed in Table C-1.

Also available (at least for reference) are special studies and reports concerned with the airphoto patterns of soils and landforms in various sections of Indiana. A comprehensive bibliography of these reports and studies is included on the following pages.

¹

For a complete discussion of these maps and reports, the reader is referred to Reference 40 listed in the Bibliography.

<u>County</u>	<u>County</u>
Allen (work in progress)	Marshall
Cass	Monroe
Clark	Montgomery
Dearborn	Newton
Elkhart	Ohio
Floyd	Parke
Fountain	Porter
Grant	Pulaski
Henry	Ripley
Jackson	Rush
Jasper	St. Joseph
Jefferson	Scott
Jennings	Starke
Kosciusko	Steuben
Lagrange	Switzerland
Lake	Tippecanoe
LaPorte	Tipton

TABLE C-1
 AVAILABILITY OF COUNTY ENGINEERING SOIL MAPS
 PREPARED BY THE USE OF AERIAL PHOTOGRAPHS

BIBLIOGRAPHY OF SPECIAL AIRPHOTO
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