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**MANUAL
ON
FOUNDATION INVESTIGATIONS
1978**



**Developed by the AASHTO
Highway Subcommittee on Bridges and Structures**

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Table of Contents

THE BODY

PART I — INTRODUCTION

	Page
GENERAL	1
PURPOSE OF MANUAL.....	1
LIMITATIONS.....	1
CONTENTS	1

PART II — RECONNAISSANCE

OFFICE RECONNAISSANCE.....	2
Study of Existing Structures	2
Study of Preliminary Plans	2
Consultation With Others	2
Review of Other Information	2
Topographic Maps	2
Geologic Maps.....	3
Agricultural Maps	4
Remote Sensing	4
Well-Drilling Logs.....	5
Formulation of Boring Plan.....	5
FIELD RECONNAISSANCE	6
Items to Observe	7
Location of Bents and Piers.....	7
Surface Soils.....	7
Gullies, Excavations, Slopes, or Stream Banks.....	7
Surface and Subsurface Water	7
Study of Existing Structures.....	8
Topography and Vegetation.....	8
Information Required by the Drill Crew	8
Verification of Boring Plan	8
Type of Equipment Needed	8
Reference Points and Bench Marks	9
Permission of Property Owners.....	9
Utilities	9
General Notes.....	10
Geophysical Survey	10
Field Reconnaissance Report	10, 11

PART III — FOUNDATION EXPLORATION

GENERAL	12
Permission of Property Owners	12
Locations of Roads, Structures, and Utilities.....	13

Table of Contents

	Page
GENERAL (Continued)	
Special Equipment	13
Layout — Surveying	13
Vertical Control	14
Tolerance in Hole Location	14
SUBSURFACE EXPLORATION PLAN	14
METHOD OF DRILLING	16
Rotary Drilling	16
Auger Drilling	17
Wash-Boring	17
Drilling by Continuous Sampling	17
Coring	18
Special Methods	18
SAMPLING	19
Split-Barrel Sampling	19
Push Barrel or Thin-Walled Tube Sampling	20
Wet Barrel or Double Wall Sampling	20
Dry Barrel or Single Wall Sampling	21
Wash Sampling	21
Retractable Plug Sampling	21
Sample Protection and Transportation	22
FIELD TESTS	22
Dynamic Field Tests	22
Standard Penetration Test	22
Cone Penetrometer Test	23
Driven Probe Test	24
Driven Casing Test	24
Static Penetrometer Test	24
In-Place Vane Shear Test	25
Other Field Tests	25
FIELD BORING LOG	25
Duties of the Logger	26
Field Identification and Classification of Soils and Rocks	27
Field Tests	28
Logging	28
Equipment and Supplies	28
Format of Field Boring Log	28
Logging Procedures	28
Groundwater Table	30
SITE CLEAN-UP	30
OPEN PIT AND TRENCH EXCAVATION	31
Open Test Pits	31
Test Trenches	31
EXAMPLE FORM	32
Typical Field Boring Log	32

Table of Contents

PART IV — LABORATORY TESTS	
	Page
GENERAL	33
GRAIN SIZE, SHAPE, AND GRADATION	33
SPECIFIC GRAVITY	35
ATTERBERG LIMITS	35
CONSOLIDATION	35
TRIAXIAL SHEAR	36
DIRECT SHEAR	36
UNCONFINED COMPRESSION	36
MOISTURE CONTENT AND IN-PLACE DENSITY	36
CLASSIFICATION	37
PART V — COMPILING INFORMATION	
GENERAL	38
FINISHED BORING LOG	38
PLOTTING SOIL PROFILES	39
ARRANGEMENT OF TEST DATA	40
CRITICAL STUDY AND IMPLICATIONS	40
FINAL WRITTEN REPORT	41
Type of Support	41
Pile Support	41
Footing Foundation Support	42
Approach Fill Considerations	42
Construction Considerations	42
EXAMPLES	43-46
Typical Finished Boring Log	43
Boring Log Legend	44
Soil Profile	45
Test Results	46



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Table of Contents

THE APPENDIX

APPENDIX A — GEOLOGY

	Page
GENERAL	A-1
BEDROCK	A-1
Origin of Rocks.....	A-1
Igneous Rocks	A-1
Sedimentary Rocks.....	A-2
Metamorphic Rocks.....	A-4
COMMON TYPES OF ROCK.....	A-5
Classification	A-5
Minerals.....	A-5
Hardness	A-5
Minimum Equipment for Identification.....	A-6
Steps in Identification of Rock.....	A-6
STRUCTURAL TYPES ENCOUNTERED IN ROCK	A-7
Terms.....	A-7
Types of Folds	A-8
Illustration of Types of Folds	A-10
Joints and Bedding Planes	A-8
WEATHERING.....	A-9
Rain.....	A-9
Frost.....	A-11
Wind	A-11
Insolation.....	A-11
TABLE OF 32 COMMON ROCKS	A-13
TABLE OF 20 COMMON MINERALS.....	A-19

APPENDIX B — SOILS

GENERAL	B-1
FORMATION OF SOILS.....	B-1
Geologic Cycle	B-1
Weathering.....	B-2
Mechanical.....	B-2
Mechanical Abrasion	B-2
Temperature Changes	B-2
Other Agents	B-3
Chemical	B-3
Products of Weathering.....	B-3
Transported Soils.....	B-4
Water-Deposited Soils (Alluvial and Marine Deposits).....	B-4

Table of Contents

THE APPENDICES

	Page
FORMATION OF SOILS (Continued)	
Wind-Deposited Soils (Aeolian Deposits).....	B-5
Volcanic Ash-Pumice	B-6
Ice-Deposited Soils (Glacial Deposits).....	B-6
Gravity-Deposited Soils (Colluvial Deposits)	B-7
Residual Soils	B-7
SOIL PROPERTIES	B-8
Physical Properties	B-8
Voids.....	B-8
Soil Moisture.....	B-8
Specific Gravity	B-9
Unit Weight	B-9
Relationships.....	B-10
Relative Density	B-11
Grain Size	B-11
Soil Particle Sizes (Chart).....	B-13
Grain Size Distribution Curves (Plot)	B-14
Grading Chart (Photos).....	B-15
Grain Sizes (Photos)	B-16
Grain Shape	B-17
Roundness Chart (Photos).....	B-19
Plasticity	B-17
Engineering Characteristics	B-18
Strength	B-18
Mohr Diagram (Plot).....	B-22
Compressibility	B-21
Pressure — Void Ratio Curve (Plot)	B-24
Pressure — Void Ratio Curve (Plot — Log Scale).....	B-25
SOIL CLASSIFICATION	B-26
Unified Soil Classification System	B-26
Coarse-Grained Soils	B-27
Less Than 5% Pass the No. 200 Sieve	B-27
GW Group.....	B-27
SW Group.....	B-28
GP Group.....	B-28
SP Group.....	B-28
More Than 12% Pass the No. 200 Sieve	B-28
GM Group.....	B-29
GC Group.....	B-29
SM Group.....	B-29
SC Group.....	B-29
Borderline (Between 5% and 12%).....	B-29
Fine-Grained Soils.....	B-30
ML Group.....	B-30
MH Group.....	B-30
CL Group.....	B-30
CH Group.....	B-30
Borderline	B-31

Table of Contents

THE APPENDICES

	Page
SOIL CLASSIFICATION (Continued)	
Highly Organic Soils	B-31
OL Group.....	B-31
OH Group.....	B-31
Field Identification.....	B-31
Coarse-Grained Soils.....	B-31
Fine-Grained Soils.....	B-32
Highly Organic Soils	B-32
Dual Classifications.....	B-32
TABLES AND CHARTS	
Description of Moisture Content	B-32
Unified Soil Classification Chart.....	B-34
Laboratory Identification Procedure (FOLD-OUT)	B-33
MANUAL TESTS FOR FIELD IDENTIFICATION.....	B-35
Silt and Clay Characteristics.....	B-36
Soil Percentage Triangles	B-37
POSSIBLE ABBREVIATIONS.....	B-38
GLOSSARY.....	B-39

APPENDIX C — TESTING

SECTION ON FIELD TESTS.....	C-1
Consistency and Density Testing By Penetrometer.....	C-1
Standard Penetration Test (AASHTO T 206)	C-1
Apparatus.....	C-1
Procedure	C-1
Discussion	C-2
Sources of Error	C-2
Cone Penetrometer Test.....	C-2
Apparatus.....	C-2
Procedure	C-2
Discussion	C-3
Driven Probe Test (Probe Point Penetrometer Test).....	C-3
Apparatus.....	C-3
Procedure	C-4
Friction Penetrometer	C-4
Nomograph.....	C-5
Static Cone Penetrometer Test.....	C-4
Soil Shear Tests	C-6
In-Place Vane Shear Test.....	C-6
Apparatus.....	C-6
Procedure	C-6
Field Calculations	C-6
Shear Vane Assembly (Drawing).....	C-11
Load Plate Test	C-7

Table of Contents

THE APPENDICES

	Page
APPENDIX C — TESTING (Continued)	
SECTION ON LABORATORY TESTING	C-7
PHOTOGRAPHS OF FIELD TEST EQUIPMENT	C-12-13

APPENDIX D — DRILLING

GENERAL	D-1
DRILLING METHODS	D-1
Rotary Drilling	D-1
Table of Bentonite Proportions	D-2
Rock Coring	D-3
Wash-Boring	D-3
Continuous Sampling Method	D-4
Auger Drilling	D-4
Percussion Drilling	D-5
DRILLING EQUIPMENT	D-5
Drilling Units	D-5
Rotary Drilling Equipment	D-6
Drill Rods	D-6
Casing	D-7
Drill Bits	D-7
Drilling Accessories	D-8
Diamond Core Drilling Equipment	D-8
Table of Drill Rods, Casing and Coring Bits	D-9
Table of Diamond Sizes	D-10
Table of Total Carat Weight	D-11
Table of Matrix Hardness	D-12
Wash-Boring Equipment	D-12
Auger Drilling Equipment	D-12
Table of Popular Size Augers	D-13
Table of Auger Heads	D-13
Table of Hollow-Stem Auger Sizes	D-14
Diamond Size Comparison Chart	D-15
Casing Bit and Shell Diameters (Table)	D-16
Set Bit and Shell Diameters (Table)	D-17
Photographs of Equipment	D-18-19

APPENDIX E — SAMPLING

GENERAL	E-1
CLASSIFICATION OF SOIL SAMPLES	E-1
Disturbed Samples	E-1
Undisturbed Samples	E-1



	Page
APPENDIX E — SAMPLING (Continued)	
FREQUENCY OF SAMPLING	E-2
ROCK BORINGS	E-2
DETAILED METHODS OF SECURING SAMPLES	E-2
Split-Barrel Sampling	E-2
Push Barrel or Thin-Walled Tube Sampling	E-3
Shelby Tube Sampling	E-3
Stationary Piston Type Sampling	E-5
Wet Barrel or Double Wall Tube Sampling	E-6
Dry Barrel or Single Wall Tube Sampling	E-7
Retractable Plug Sampling	E-7
Rock Core Borings	E-8
PRESERVING SAMPLES	E-8
Split-Barrel Samples	E-9
Push Barrel or Thin-Walled Tube Samples	E-9
Wet Barrel or Double Wall Tube Samples	E-10
Retractable Plug Samples	E-10
Rock Cores	E-10
PHOTOGRAPHS OF EQUIPMENT	E-11

APPENDIX F — GEOPHYSICAL EXPLORATION

GEOPHYSICAL EXPLORATION	F-1
Geophysical Investigation	F-1
Seismic Methods	F-2
Seismic Problems and Limitations	F-5
Resistivity Methods	F-6
Resistivity Problems and Limitations	F-6
 BIBLIOGRAPHY	 BIB-1

This Manual is a revision of the 1967 Manual on Foundation Investigation. The revision includes the use of both U.S. Customary and the exact International System of Units (SI) dimensions.

PART I

INTRODUCTION

GENERAL: Since the stability and safety of a structure depend upon the proper performance of its foundation, it is evident that the first step in the successful design of any structure is that of achieving a proper foundation design.

Soil mechanics is the basis of foundation design, and before its laws can be properly applied, it is necessary to have knowledge of the distribution, types, and engineering properties of subsurface materials. Hence, a careful foundation investigation can minimize the need for overdesign (an uneconomical practice employed to compensate for lack of knowledge of foundation material) and reduce the cases of underdesign (and the resulting failures attributed to the so-called "unforeseen" soil conditions).

Therefore, the purpose of foundation investigation is to provide the designer with information on the engineering properties, including load carrying capacity, of the natural material available for use as the foundation of a structure. This information will permit the selection of the best suited foundation material and will affect or govern the type and design of the structural foundation.

PURPOSE OF MANUAL: This Manual is not to be used for any design purposes, but it is intended to provide a logical approach to the investigation problem by describing suggested procedures for the execution of the investigation. These procedures are intended to carry the investigation from its original conception through the various phases of office, field, and laboratory work, analysis by the Soils or Foundation Engineer, and thence to the desk of the structural designer.

LIMITATIONS: It is realized that any foundation investigation will leave certain areas unexplored. It is further realized that there are an infinite number of conditions to be met and that it would be impractical to attempt to provide a set of rules for all possible cases. Thus, neither this Manual nor any manual will answer all foundation investigation problems. It leaves many areas where individual judgement and experience must be utilized. The procedures set forth herein will not be sufficient to meet the needs of all organizations; however, the Manual is sufficiently broad and flexible to lend itself to any revisions as may be required by its users.

CONTENTS: This Manual is divided into two portions — The Body and The Appendices. The Body includes a detailed, step-by-step procedure for a foundation investigation.

The Appendices are provided to supplement the methods and concepts outlined in The Body. Included is auxiliary material on Geology, Soils, Field Tests, Laboratory Tests, Drilling, Sampling, and Geophysical Exploration, as well as a Bibliography.

PART II

RECONNAISSANCE

A field investigation can be more intelligently planned if a review is made of available information on the area before proceeding with the actual soundings and borings. This review can be divided into the two phases, Office Reconnaissance and Field Reconnaissance.

OFFICE RECONNAISSANCE: In the office phase, the following steps and sources of information are recommended. It is probable that all of these sources will not be utilized on any one site. However, all of them are possible sources of good information which is available much more cheaply than that obtained from drilling and sampling.

Study of Existing Structures: A review of plans of other existing structures in the area, along with a review of the construction records of these existing structures will generally provide very valuable information at minimum expense.

Study of Preliminary Plans: Often preliminary sketches and plans depend upon foundation data, but where the preliminary plans are prepared, the engineer in charge of the foundation investigation should become completely familiar with the proposed structure by studying these plans and designs. He should discuss them with the design engineers and determine the approximate magnitude of the loads to be transmitted to the founding material.

Consultation with Others: Many organizations, public agencies, etc., will have a backlog of information already compiled on certain areas. This information should be consulted first. Experience gained by other engineers as well as contracting firms who may have completed work on similar structures in the same general area should also be determined and utilized.

These sources could be invaluable in obtaining general information on soil and rock types and foundation and groundwater conditions which could be expected in the later phase of field exploration. Also it is possible that previous experience will reveal acceptable foundation solutions for the problems at hand.

Review of Other Information: Other information pertaining to the site area could be obtained from such sources as different types of maps, records of adjacent railroad and of underground utility construction, aerial photographs and well-drilling logs. A study of available information of this type would justify the time taken. These maps and other sources are discussed below.

It is important for the Engineer to recognize the limitations of various types of maps. Some maps show considerable detail, while others are of a reconnaissance type showing more generalized conditions.

Topographic Maps. The topo map is valuable in the design and construction of most structures, and it is of considerable value in the ex-

ploration of foundation material for highway structures. The locations and elevations of exploratory holes, outcrops, and erosional features can be placed on the map. The land forms portrayed by the contours indicate to some degree the type of geologic conditions.

Geologic Maps. On these maps, rock and soil masses are identified by name and geologic age. The smallest unit commonly mapped is a formation, but smaller subdivisions such as members or beds may be delineated. A formation is an individual bed or several beds which extend over a fairly large area and which can be clearly differentiated from overlying or underlying beds because of a difference in lithology, structure, or age. The extent of these formations is indicated by means of letter symbols, colors, and symbolic patterns.

The most important detail to be obtained from a geologic map is the particular formation on which a structure is to be located. With experience, certain subsurface characteristics may be deduced from and associated with various formations. For example, soft clay layers may become associated with certain limestone formations; the knowledge of which would then alert the drill crew to be especially watchful for these layers and to have the necessary sampling tools for taking undisturbed samples of the clay. Other formations, such as badly weathered or metamorphosed igneous rocks, may be subject to shear failure under foundation loads. Bedding dips or slopes in sedimentary formations may also present areas of weak support for foundation loads. Other formations may become noted for safely supporting spread footings, a fact which could reduce the number of borings otherwise required in the boring plan.

After a specific formation has been identified, some of its characteristics may be obtained from geologic publications. The majority of these are published by the United States Geological Survey and by the State Geological Surveys.

Geologic maps often carry as marginal data a composite columnar section and one or more geologic cross sections which are a graphic representation of the various strata along an arbitrary line usually marked on the map. However, the sections are somewhat hypothetical and are usually exaggerated vertically. They must be used with caution, as those prepared solely from surface data may be erroneous, while those prepared from boring records or mining evidence are more reliable.

Engineering information can be obtained from geologic maps if the user possesses a knowledge of the fundamentals of geology and an understanding of how engineers use geologic facts in design and construction. Such information is valuable in preliminary planning activities, but it is not a substitute for detailed explorations in the field phase of the investigations.

The U. S. Geological Survey now publishes a series of geologic quadrangle maps which replace the earlier folios of the Geologic Atlas of the United States, published from 1894 to 1945. This new series consists of geologic maps with structural sections, formation outcrops,



faulting, and other graphic means to show geologic factors in relation to scientific, economic, and engineering purposes.

Agricultural Maps. The Soil Survey Division of the United States Department of Agriculture, now a part of the Soil Conservation Service of the USDA, has since 1899 prepared and published, and has currently underway, surveys leading to soil maps and bulletins for much of the United States. In order to apply them to explorations of foundations, some knowledge of the pedological system of soil classification is necessary. However, these maps and reports, which since 1957 have included a chapter on "Engineering Data and Interpretations," are mainly a tool which can be used as a general guide to assist in planning and conducting a soil survey, and they may be of limited value in foundation work due to the shallow depth explored.

Remote Sensing. Aerial photographs, produced by remote sensors, can provide an overall view of a site. Aerial photos can reveal general information on topography, vegetation, access, etc; of an area. In addition, some idea of soils and subsurface conditions can be gained from a study of these photos. Three basic principles relative to the identification of soils and subsurface conditions from aerial photographs are as follows...

An aerial photo accurately reproduces the physical features of the earth's surface and records natural as well as man-made features. In doing this, it records the results of natural processes which have been active in the development of residual soils, and it records the occurrence of transported soils by reflecting surface and subsurface features.

Similar materials reflect similar patterns, and unlike materials reproduce unlike patterns. Because of this, surface and subsurface features can be grouped together in patterns which are unique for a given type of soil and environment.

Soil patterns as reflected by aerial photographs are repetitive in nature, within limits.

Remote-sensing makes use of cameras, optical-mechanical scanners, and radar and microwave imaging systems. Many remote sensors, however, are not readily applicable to engineering purposes, especially for knowledge of subsurface conditions.

The most promising and useful remote sensors for site investigations are:

1. Panchromatic Photography
2. Color Photography
3. Infrared Photography
4. Infrared Imagery
5. Radar Imagery

Geologic features which may be highly significant to the location or performance of structures can sometimes be identified. In many instances, joint systems, land slides, fault zones, folds, limesinks, and other structural features can be identified more readily on the photo than on the ground. Vegetation types and density can frequently alert the interpreter to subsurface moisture and rock conditions that are not apparent from surface reconnaissance. The importance of these fea-

tures in the foundation design of bridges and other structures is obvious. It must be recognized that photo interpretation is usually applicable only to those features which develop recognizable surface expressions such as drainage patterns and alignment of ridges or valleys, although the general attitude, bedding, and jointing of exposed rock strata and the presence of dikes and intrusions can often be interpreted.

Panchromatic, color and infrared photography, and infrared and radar are all useful as planning tools for site exploration. Remote sensing data, however, is not reliable enough to use in foundation design. Aerial photographs should be used only to supplement boring logs and laboratory tests results.

Additional information may be obtained at selected locations through ERTS (Lansat) Information. This information is usable generally for a regional-type study and is, under its current development, unsatisfactory for specific site analysis.

Well-Drilling Logs. When available from local drilling contractors or other sources, well-drilling logs can be useful indicators as to the nature of the materials in the proposed foundation. Unlike maps and aerial photos, these logs are usually unrecorded, and there may be no comprehensive listing of those available in any one area.

However, some states do require the contractors to record the different strata encountered, and often these well-drilling logs are consolidated and published in bulletins by the U. S. Geological Survey or by state geological agencies. These records may be sufficient to indicate the major soil and rock formations near the particular area.

Formulation of Boring Plan: During the latter phases of the office reconnaissance, a boring plan should be made for review during the field reconnaissance. A boring plan, which includes the spacings, locations, depths of boring and sampling interval should be prepared before any borings begin. There are many variables involved in the formulation of this plan, and it requires considerable experience to schedule enough holes without excessive or inadequate exploration. Other factors which may be involved are personal judgement, personal preference, organization policy, and certainly a knowledge of the proposed structure. The objective should be the development of a maximum of subsurface information through the use of a minimum number of holes.

However the original plan is determined, it should be closely examined on the field reconnaissance and adjusted as may be necessary before it is given to the drill crew. Although the drill foreman should have a firm plan to follow, it must be realized that the boring plan is not only subject to revision after the field reconnaissance but also during the exploration work itself.

Boring spacings depend on the uniformity of the soil strata and on the loading conditions. Erratic subsurface conditions require closely spaced borings, whereas uniform soil conditions require a maximum spacing. Structures sensitive to settlements and structures subjected to heavy loads require extensive subsurface knowledge; therefore, borings should be closely spaced. Knowledge of the regional conditions is the best guide to the necessary spacing of borings.



Some of the more general "rules" used in formulating a plan are as follows: Limestone formations may require more borings than will other types due to their irregular weathering, and it is often found necessary to make one boring at each footing. In areas underlain by igneous rock and metamorphic igneous rock, as few as one boring per bent will often suffice, while in areas of shallow ocean deposits, one boring for every other bent (for spans up to 60 feet (18.288 m)) will often be adequate. In alluvial valleys and areas of glacial till, general rules seldom are possible. Experience in the area and knowledge of the local geology are the best guides. When spread footings on soil are to be used, at least one boring per bent is suggested for use in all regions. When wide, high approach embankments are used at bridge ends, at least one boring should be made at each embankment to determine the problems associated with settlement and stability of the embankment. Usually these embankment borings can be combined with those made for the end bents or abutments of the structure.

One boring is usually made at the centerline of each end bent or abutment. When rock is encountered at shallow depths, additional, transverse borings should be made.

The required depth of borings will vary and several empirical rules are available for determining depth. A common practice is to advance the borings to a depth where the added stress, due to the applied structure load, will be 10 percent of the existing overburden stress. The use of Bouissinesq or Westergaard analysis can be used to determine the stress distribution due to the structure.

The sampling interval will depend on the homogeneity of the subsurface material. A general rule to follow during subsurface drilling is to take a sample at every noticeable change in soil type, consistency or strength. Erratic soil conditions may require almost continuous sampling, while uniform conditions will allow a sampling interval of approximately 5 feet (1.524 m).

Sufficient information must be obtained so that the report submitted to the structural designer will have the information necessary to determine the most economical foundations. Thus, the boring plan should include sufficient borings, samples, and insitu tests for the drill supervisor to adequately investigate the site.

In addition to conventional boring programs, evaluation of geophysical programs should also be made. (See appendix "F"). This can generally consist of cross-hole surveys, seismic surveys, electromagnetic subsurface profiling or where the site is below the water level, acoustic sub-bottom profile. These geophysical methods are special techniques and should be utilized in the field only by personnel experienced in their use.

FIELD RECONNAISSANCE: After the office phase of reconnaissance has been completed, the field phase should commence with a visit to the proposed bridge site. It should always be made by an engineer, preferably the Soils or Foundation Engineer who will complete the foundation report. Whenever possible, it is desirable that this engineer be accompanied by the driller or the drill foreman.

It is recognized that in some instances the field reconnaissance phase may be combined with the drill crew's operations. However, when the field reconnaissance is economically justified, it is better to make it before scheduling the drill crew's work at the site.

The field reconnaissance has two real purposes as follows...

- ... To allow an experienced observer to view the site and record any facts which will affect either the foundation design or the boring plan.
- ... To gather information needed by the drill crew. If the field reconnaissance did no more than prepare the drill crew for the site, then that alone would justify its use.

Items to Observe: Valuable information can often be obtained by viewing the surface indications of subsurface conditions. Notes on items to be observed are as follows:

Location of Bents and Piers. The designer's proposed location of the bents and piers should be observed. Later troubles may be prevented by recommending a shift of the substructure units at this early date. Examples of this are bents whose proposed locations are on river banks of questionable stability or bents which may be moved slightly and placed upon rock.

In low, marshy areas where approach fills are to be placed over soft, compressible material, a lengthening of the bridge or special treatment of the poor soil may be in order. If these situations arise, the information should be reported from the reconnaissance to the Bridge Engineer, and the preliminary plans should be revised before the drill crew works the site.

Surface Soils. Surface soils are easily revealed through the use of a shovel or post hole diggers. These soils may sometimes be identified as belonging to some particular formation, and usually they indicate the underlying material.

Stream deposited soils may indicate stream characteristics. The presence of boulders on a small stream indicates high stream velocity and hence possible scour problems. The presence of boulders in the soil profile often leads to serious problems in foundation drilling and driving of piles.

Rock exposures near the bridge site should be studied. Extending a rock outcrop in accordance with its strike and dip may tell whether or not a bent is to be founded on rock. Strike and dip are discussed in APPENDIX A — GEOLOGY.

Gullies, Excavations, Slopes, or Stream Banks. Any cut or hole in the ground near the bridge site is a subsurface window, and for its depth, it will provide more information than a bore hole since it may be examined in detail. Soil type and distribution as well as rock existence and type are often quickly and easily available from these sources.

Surface and Subsurface Water. The presence of either surface or subsurface water is an important factor in both foundation design and preparation of boring plans. All surface flows should be noted, and all opportunities should be taken to observe the groundwater level. Wells

and deep holes or excavations are good sources for locating the ground-water table.

Study of Existing Structures. The existing structures within an area are valuable sources of information. A very close examination of them with regard to type of support, apparent settlement, load, location, and age will yield a wealth of data. The foundation plan and boring logs for these structures may be available, and they can be used in conjunction with past experience and surface observation.

Topography and Vegetation. Topography is important in determining the location of bridge substructure. To some extent, it is indicative of subsurface conditions. For example, in narrow, steep stream beds, rock is likely to be near the surface with little overlying stream-deposited soil. On the other hand, wide, flat valleys indicate deep deposits. Topography notes are also of importance to the drill crew's preparation for the site. They can be advised as to where the use of truck-mounted drills is possible and where portable or winched equipment will be necessary.

To some extent, vegetation is indicative of subsurface soil and water conditions. For example, growth is apt to be rank and dark green in areas where there is groundwater seepage. In some localities, the growth of certain kinds of trees and shrubs can be linked with areas having thin overburden and rock. However, the proper consideration of vegetation in the prediction of subsurface conditions requires considerable experience on the part of the observer, which can be gained only after viewing many sites and comparing them with the boring results.

Information Required by the Drill Crew: The recording of information needed by the drill crew is more definite and detailed. They need to know how to get to the site, where to drill, what equipment to take, and what difficulties to expect. It is not intended that the drill crew's work be done by the reconnaissance party, but as many of the time-consuming preparations as possible should be made during reconnaissance before the drill crew's arrival at the site. The drill crew's time should be spent in drilling and sampling and not in sending back to headquarters for more equipment or in looking for the site. Generally, the type of information needed is as follows:

Verification of Boring Plan. The proposed locations of borings should be checked for accessibility. Desirable deletions, additions, and relocations should be made as are necessary to better suit the crew's capabilities and to add completeness to the subsurface information.

Type of Equipment Needed. Notes should be made as to which type of drilling is best suited to the site (rotary, auger, etc.). All sites should be explored by the method most applicable to the field conditions, and accessibility of the site is an important consideration in determining the type of equipment needed. The reconnaissance should determine if auger drilling is applicable to the site, which will require a decision as

PART II — RECONNAISSANCE

FIELD RECONNAISSANCE

to whether or not an auger hole will remain open for sampling. This decision will have to be based upon knowledge of the area as well as surface indications. If difficulty in "holding the hole" is anticipated, then the use of a rotary drill rig in conjunction with casing or drilling mud should be set up for the job, or the use of the hollow-stem augers. If the wet drilling method or wash-boring sounding is proposed for the site, notes should be made on the nearest source of water and on the size of pump and length of hose required. Any extra equipment which is likely to be needed such as special drilling bits, coring bits, portable water tank, or sampling equipment should be noted; however, the usual equipment carried by the crew need not be listed.

If any borings are to be located in a stream bed, the reconnaissance should note the size of the barge best suited for the job, details of anchoring the barge (size and length of cable or length and number of spuds), and whether or not special permits will be needed before the barge or cable may be positioned (navigable or recreational crossings). Information should also be obtained as to the difficulty of launching the barge, and if some site preparation is necessary, arrangements should be made to have a bulldozer or other needed equipment sent to the site. The type of equipment might be influenced by the season of the year when borings are to be made. The winter season may be selected for boring some sites whose access might be facilitated by frozen ground.

Reference Points and Bench Marks. The reconnaissance should determine if reference points and bench marks are in place adjacent to the site and properly referenced on the plans. The boring locations may be laid out by the reconnaissance party, by the drill crew, or by others. If other than simple surveying is necessary, it should be done by others, and the reconnaissance party or the drill crew should never be tied up with complex surveying assignments.

If the boring locations are shown on a site plan having contours of close interval, bench marks may not be needed.

Permission of Property Owners. If the drilling is to be done on property belonging to others or if access is through property belonging to others, permission to do the work or to get to the work should be obtained in advance by the reconnaissance party if possible or by others if necessary. A more detailed discussion of this important matter will be found in PART III — FOUNDATION EXPLORATION..

Utilities. Underground or overhead utilities located at the site should be accurately shown on the plans or their locations should be staked on the ground. Otherwise, the names of agencies or people to call before work starts should be shown on the drill foreman's work plans.

Maps should never be used to locate utilities without additional field verification, preferably by a representative of the utility. A record should be made of the person, including his title or position, that made the field verification.



General Notes. General notes should be made concerning the best route to the site and any other information which could be of value to the drill crew. If exploration methods other than drilling are applicable to the site, the locations and types of tests should be decided upon during the reconnaissance.

Geophysical Survey. The field reconnaissance should consist of a geophysical survey of the site. While a visual survey of the site is to obtain information about the surface geology and topography, the geophysical survey is initiated to obtain subsurface information. The use of geophysical methods provides information on the depths to the soil and rock layers, the homogeneity of the layers, and the type of soil and rock present. This information can be used to supplement the boring plan (See Appendix F).

Field Reconnaissance Report: The reconnaissance is facilitated by the use of a check list or form such as that shown at the conclusion of this Part.

One rule for a good reconnaissance is to make all decisions concerning the boring plan and the drill crew while at the site. The person making the reconnaissance should be competent and willing to make these decisions then and there.

BRIDGE FOUNDATION INVESTIGATION
FIELD RECONNAISSANCE REPORT
STATE HIGHWAY DEPARTMENT OF

PROJECT NO: _____ COUNTY _____ STA. NO. _____

REPORTED BY: _____ DATE _____

1. STAKING OF LINE

____ Well Staked
____ Poorly Staked (We can work)
____ Poorly Staked (We must replace)
____ Request Division to Restake

2. BENCH MARKS

In Place: Yes _____ No _____
Distance From Bridge - Ft. (m) _____

3. PROPERTY OWNERS

Granted Permission: Yes _____ No _____
Remarks on Back _____

4. UTILITIES

Will Drillers Encounter Underground
Utilities? Yes _____ No _____ Maybe _____
At Which Holes? _____
What Type? _____
Who To See for Definite Location _____

5. GEOLOGIC FORMATION

6. SURFACE SOILS

Sand _____ Clay _____ Sandy Clay _____
Muck _____ Silt _____ Other _____

7. GENERAL SITE DESCRIPTION

Topography
Level _____ Rolling _____ Hillside _____
Valley _____ Swamp _____ Gullied _____
Ground Cover
Cleared _____ Farmed _____ Buildings _____
Heavy woods _____ Light woods _____
Other _____
Remarks on Back _____

8. BRIDGE SITE

Replacing _____
Widening _____
Relocation _____
Check Appropriate Equipment
____ B-61 Mobile Drill
____ B-52 Mobile Drill
____ Failing 1500
____ Truck Mounted Skid Rig
____ Skid Rig
____ Rock Coring Rig
____ Wash Boring Equipment
____ Water Wagon
____ Pump
____ Hose _____ Feet (m) _____

8. BRIDGE SITE - Cont'd.

Cut Section - Feet (m) _____
Fill Section - Feet (m) _____
If Stream Crossing:
Will Pontoons Be Necessary? _____
Can Pontoons Be Placed In Water Easily? _____
Can Cable Be Stretched Across Stream? _____
How Long? _____
Is Outboard Motorboat Necessary? _____
Current:
Swift _____ Moderate _____ Slow _____
If Present Bridge Nearby:
Type of Foundation _____
Any Problems Evident In Old Bridge _____
(describe on back)
Is Water Nearby For Wet Drilling -
Feet (m) _____

9. GROUND WATER TABLE

Close To Surface - Feet (m) _____
Nearby Wells - Depth - Feet (m) _____
Intermediate Depth - Feet (m) _____

10. ROCK

Boulders Over Area? Yes _____ No _____
Definite Outcrop? Yes _____ No _____
(show sketch on back)
What kind? _____

11. SPECIAL EQUIPMENT NECESSARY

12. REMARKS ON ACCESS

Describe Any Problems on Access

13. DEBRIS AND SANITARY DUMPS

Stations _____
Remarks _____



PART III

FOUNDATION EXPLORATION

GENERAL: After the reconnaissance has been completed, the results should be given to the foreman of the drill crew scheduled to make the foundation exploration at the site.

Briefly, the foundation or site exploration consists of making the borings and collecting the pertinent samples. In this Manual, drilling and sampling will be discussed separately. Drilling is defined as that process which advances the bore hole. Sampling is that process wherein samples of the subsurface materials are obtained.

Due to the widely divergent geological soil and rock conditions encountered in the various sections of the United States, it is impractical to outline a methodical procedure to follow in making all foundation explorations. Each job site must be studied and explored according to its subsurface conditions, and the Engineer or Geologist in charge should endeavor to furnish complete data such that an impartial study of practical foundation design types can be made. The size and type of the proposed structure will also be dominant factors in influencing the methods and the extent of the exploration.

Permission of Property Owners: The first problem faced by the drill crew foreman is that of right-of-entry of equipment and personnel on private property. It has been recommended in PART II — RECONNAISSANCE that this problem be solved in advance of the exploration work. If the necessary arrangements are not made in advance or if a field reconnaissance is not made, then the owner's permission should be sought and obtained before entering upon property other than existing right-of-way of the Highway Department. This permission, written or verbal, should be arranged by an authorized representative of the State, and it should cover rights of access to the work, rights-of-entry on the site itself, and the rights to perform the actual exploratory work. These rights should clearly cover the use of both personnel and equipment.

Good relations should be established and maintained with the land owner by informing him of the work to be done and the methods to be used. He should be assured of minimum inconvenience and damage to him and to his property as a result of the drilling operations. When the work is scheduled, due consideration should be given to the weather, growing crops, or other obvious land use. It is important to realize that the public's opinion of an engineering organization is frequently based upon the conduct and general attitude of the field crews personnel.

Regardless of the procedures followed, and whether or not they are handled on the reconnaissance or later, the drill foreman should be advised as to his rights-of-entry, and he should not make entry until he is authorized to do so.

In cases where explorations are to be made within the limits of navigable or recreational waters or wetlands, the duly authorized representative of the State should advise the authority having jurisdiction over such waters of the work contemplated and procure its approval for entry. Conformation with the practices or regulations of the governing authority should be assured.

Location of Roads, Structures; and Utilities: As has been previously recommended in PART II, these data should be obtained during the field reconnaissance, and they positively should be located on the preliminary layout or the drill foreman's work plans. If the drill foreman cannot satisfy himself as to the location of utilities (gas, water, sewer, electrical, telephone, etc.), he should call the appropriate owner of the installation, and these names and telephone numbers should be shown on his work plans.

In the event that the locations are known, it is still good public relations to keep the installation owners advised of operations and to exercise every precaution to avoid damage and interruption of services.

In urban areas where the utility problem is more complex, it is desirable to have the utilities personnel come to the site and locate their lines for the drill crew by the use of special detection devices, location maps, digging, or other means.

Special Equipment: Arrangements for the special equipment requirements noted during the field reconnaissance (or otherwise determined) should be made before going to the site. This equipment may consist of a bulldozer needed for the construction of access roads and site clearing, as well as for assisting the drilling equipment to get on the hole locations.

The special equipment may consist of barges and their necessary equipment which are required on locations such as large streams, rivers, lakes, or bay crossings.

Layout — Surveying: Before the arrival of the drill crew at the exploration site, enough survey control (usually centerline alignment stakes at 100 foot (30.480 m) stations and one bench mark will suffice, although some organizations prefer two BM's to aid against error) should have been previously established by others so as to allow the engineering technicians, soils engineer or, in certain instances, the drill crew chief to lay out the boring locations with simple surveying and determine the elevation of the ground surface at each boring location. As previously noted under Reference Points and Bench Marks in PART II — RECONNAISSANCE, the drill crew should never be tied up with complex surveying assignments, and this Manual strongly emphasizes and endorses this principle, even though other procedures may be employed by the various highway departments or organizations. Some will prefer to have the boring layout made and elevations determined during the field reconnaissance, while some will have the actual layout done by others before exploration or by the drill crew after their arrival at the site.

The hole locations should be staked in conformity with the boring plan, and the stakes could indicate the hole number, centerline station, offset distance, and ground elevation. Additional holes may be located and drilled if it is deemed desirable to determine the subsurface conditions over a wider area.

The optimum location of the holes with respect to the limits of the proposed footings varies from organization to organization. Some require the hole to be outside of the footing limits, while others have no objection to drilling within the footing area. Likewise, the manner of numbering holes

varies with the organization, i.e., most prefer to pre-number them when the boring plan is formulated, while others prefer numbering consecutively in the order as drilled.

Vertical Control: The records of explorations are related to depth and to actual elevations as well, and good control of the leveling work and depth measurements is imperative to insure accurate, reliable reports. To help achieve this accuracy, temporary bench marks and working points will have to be developed. Drilling from or through water as opposed to drilling on dry land will present different problems.

Usually, when drilling on land the control is established by obtaining the ground elevation to within ± 0.10 foot (.031 m), and the depth below ground is obtained by using the known drill rod or auger lengths, or by marking casings in one foot increments with keel.

When drilling from bodies of water having little or no fluctuation in the water level, the water surface may be used as a datum. Occasional checks on the surface elevation should be made.

When drilling from bodies of water which rise and fall rapidly (such as tidal water or the downstream discharge of a hydroelectric plant), the establishment of control is difficult. In this case, one method used is to mark a known elevation on a spud and use this mark as a working point for measurements. When spuds are not used, a less accurate control can be established by using the stream bottom as a working point and frequently measuring the water depth. Where more accurate elevation readings are required, a tide board fixed to piling or other structures near the shore can be established and referenced to a known datum. This tide board should be marked in increments of one-tenth of a foot (.031 m).

Tolerance in Hole Location: It is suggested that there should be some tolerance in hole location, both in staking the hole and in placement of the drill. A staked location of within ± 1.00 foot ($\pm .305$ m) is recommended. The driller should drill at the stake, but he also should be allowed a tolerance of ± 1.00 foot ($\pm .305$ m) from the stake. Thus an accumulative error of ± 2.00 feet ($\pm .610$ m) maximum from the planned location is proposed, but it seems reasonable enough for general use.

During the exploration phase, it may be necessary to shift the locations of some holes due to local conditions or changes in engineering plans. The revised locations of these holes (and the location and number designation of any new or additional hole) should be carefully plotted on the preliminary layout, and the reason for the shift (or additional hole) should be noted on the field boring log.

SUBSURFACE EXPLORATION PLAN: The work necessary to obtain foundation exploration data in the field as well as in the laboratory should be carried out adequately enough so that the report submitted to the structural designer will have the information necessary to determine the most economical foundation. Therefore, the completed exploration work needs to include sufficient borings, sampling, and field testing, and each organization should have certain standard

PART III — FOUNDATION EXPLORATION

SUBSURFACE EXPLORATION PLAN

procedures or practices for the drill foreman to follow to insure the collection of this information.

The number of holes and their tentative spacing have been discussed in general terms in PART II — RECONNAISSANCE and in the GENERAL portion of this Part. It is a difficult subject to pinpoint in exact figures for the many reasons previously noted. In lieu of following a previously formulated boring plan based upon the complexity of geological conditions, pier or bent spacing, etc., some organizations may prefer a general procedure involving a maximum hole spacing. When this procedure is used, it is the responsibility of the soils engineer to drill additional, intermediate holes as required to clarify and pinpoint soil and rock elevations and strength determinations. Geologic maps and past experience can be utilized as aids in locating these intermediate borings.

The organization should have certain standard sampling intervals. For example, it may be the policy to take a standard penetration sample for each 2-1/2 feet (.762 m) of advancement and to take Shelby or thin-wall samples whenever soft clays or silts are encountered.

Another commonly used plan is to sample each 2-1/2 feet (.762 m) to a distance 15 feet (4.572 m) below the proposed footing and then to sample at 5 feet (1.524 m) intervals thereafter. In any event, certain standard practices should be established for the driller so that he will know when to make a field test and when to take the various types of samples.

This Manual considers drive samples such as those resulting from Standard Penetration Tests as adequate in sands. The design of foundations located in sands may be based upon the results of drive tests such as Standard Penetration Tests and Cone Penetrometer Tests. Undisturbed samples should be taken in silts and clays, and the design of foundations located in such materials should be based upon the results of laboratory tests.

Consideration should be given to the utilization of special testing procedures to evaluate the dynamic properties of loose soils which may be subjected to liquefaction in addition to standard penetration testing. Generally, this should be considered in an area where the sands are loose in nature.

Where the formations encountered (rock, shale, or other high bearing value materials) indicate the use of spread footings or drilled shafts, the first hole should be carried to one and one-half times the depth of the proposed footing or shaft to adequately investigate the possibility of boiling of the foundation material during construction. Where drilled shafts are a potential solution, samples should be obtained at the anticipated founding elevation to evaluate the ability to form a bell in the event they are required. For formations where piling are to be used or may be used, the exploration should be carried to 15 to 25 feet (4.572 to 7.620 m) below the probable pile tip elevations unless hard rock is encountered. An estimate of the probable pile tip elevations can be made from the results of the penetration tests and correlation graphs. When there is doubt about the type of foundation to be used, the borings should be extended to cover the deepest possibility.

Where the use of footings or shafts is indicated, the depth at which the first sample will be taken should be determined by the driller before the boring is started. The ground elevation should be compared with the probable or proposed footing elevation, and the first sample should be taken at no lower than the highest elevation at which the footing may be placed. When trestle pile bents

are proposed or likely, sampling should begin at or slightly below the ground surface.

Generally, it may be the policy that no undisturbed sampling for laboratory tests should be attempted on the first hole. After its completion, it is possible to formulate a tentative plan of procedure for the remainder of the site exploration. Also, since there may be only little knowledge of the exact nature of subsurface conditions, it may be the policy that the first hole should be sampled at closer intervals than the remainder of the borings. Those organizations using the Dry Barrel Sampler or the Wet Barrel Sampler may have a policy requiring that the first hole be drilled carefully for 100 percent core recovery, if practicable.

A complete soil and rock classification and log record should be completed for each test hole. This is discussed in the FIELD BORING LOG of this Part.

Briefly then, recommended bridge foundation exploration procedure consists of...

- advancing the hole into the ground with various drilling tools,
- performing the Standard Penetration Test, Cone Penetrometer Test, Vane Shear, Pressure Meter Tests, or other in-situ tests,
- withdrawing samples for soil and rock classifications and for field and laboratory testing,
- entering all information on the drilling report or field boring log.

METHOD OF DRILLING: There are several factors which will enter into the selection of the method of drilling for a particular site. Some of these factors are the accessibility of the site, availability of equipment, soil and groundwater conditions, and probability of the occurrence of rock.

There are various drilling methods and types of equipment described in APPENDIX D — DRILLING. The text herein will be limited to general remarks on drilling methods and equipment and the appropriateness of their use.

Rotary Drilling: Using this method and equipment, practically all foundation materials can be successfully explored for soil and rock classifications and for sampling. The method works well at almost any site, and almost all types of sampling fit well into a rotary drilling program. Thus the rotary drill is one of the most important units of equipment for bridge foundation exploration.

If rock is encountered, it can be easily cored with a rotary rig. Core drilling is actually a further refinement of rotary drilling in that a core barrel is drilled into the ground to recover a core sample of rock or soil.

The dependability and accuracy of the exploration data obtained are largely determined by the proper application of the sampling tools and field testing equipment, the percentage of sample or core recovery, the experience of the drilling crew, and the accurate logging of the soil and rock encountered.

Lost cores generally represent soft or shattered rock, clay layers, etc., whereas recovered portions represent the better material. The recovery of a high percentage of core will provide a continuous section of the materials being drilled. Cores indicate the character and composition of

the various strata, with evidence of spacing and tightness of joints, faults, and other structural details. Rotary drilling is also well adapted to the use of drive samplers and push samplers, as well as core samplers.

The main disadvantages of the rotary drilling method are that water is required, and heavy equipment is generally required. However, small skid rigs are available for use in marshy or other areas where use of the larger, heavier equipment would be difficult or impossible.

Auger Drilling: This method of drilling can be used for any purpose where disturbed samples are satisfactory for soil classification and sampling. It is used more widely in making linear soil surveys than in foundation investigation, although it is a fast method for advancing a hole and does not usually require the use of water. It is also valuable in advancing holes to depths at which samples can be obtained with thin-wall samplers and split-barrel samplers. Auger holes are of particular value in those locations where the use of drilled shafts is being considered.

However, from a practical standpoint, the depth of auger explorations is limited by the material encountered as auger use is not well suited to sites having granular soils and high groundwater tables, although the use of hollow-stem augers gives this drilling method more flexibility. When hollow-stem augers are used below the water table, care should be taken to maintain a proper water differential to prevent sand from running up into the hollow stem. If sand is allowed to run up into the hollow stem, standard penetration results will not be reliable. See APPENDIX D — DRILLING. If rock is encountered, the drilling machine generally must be modified before the rock can be cored, though with hollow-stem augers, the coring stem and bit can be inserted and the rotary power transferred from the auger to the coring bit. It is not suitable for drilling from floating platforms.

Augers operate best in loose, moderately cohesive soil, and care must be taken to prevent the soils from falling from the auger back into the hole as withdrawal is made.

Wash-Boring: This term indicates two different procedures. First, it may indicate a sounding procedure by which a pipe is jetted into the ground with or without an outside casing. The work is done by hand, and no samples other than wash samples are recovered. Boulders, large gravel, or debris cannot be penetrated, and at its best, this method is inaccurate. Care should be taken in the interpretation of the results of such work, and the wash-boring sounding method should be used only after sober consideration of the use to which the boring data is to be placed.

The second procedure indicated by this term is a drilling method. It simply means that a drill hole is advanced between sampling intervals by the washing and chopping action of a bit. Driven or other types of samples are recovered at intervals and are used as a basis for logging the hole. This is an acceptable exploration method.

Drilling By Continuous Sampling: When this method is used, the hole is advanced by the continuous taking of samples. A thin-wall sampler or core barrel is pushed or drilled for a certain distance (usually not more than



30 inches (.762 m)) by the drilling machine. Then the sampler is withdrawn from the hole, and its contents are forced out by hydraulic pressure from the pump on the drilling machine. Where it is desired to transport the sample to a soils testing laboratory, care must be taken to seal the sample immediately in as undisturbed a condition as possible in a water-tight carton or sealed-off sampler tube.

The samples obtained may be subjected to field tests, or they may be packaged and sent to the laboratory for testing, where they are used for all types of tests.

When the samples are to be subjected to strength and consolidation tests, the samples must be handled with extreme care, and they should be left intact in the sampling tubes and readied for shipment as described in APPENDIX E — SAMPLING, under PRESERVING SAMPLES.

Since the entire bore hole is inspected, in effect, by means of the samples, this is a very accurate method of obtaining subsurface information. However, it is expensive and somewhat limited in its area of application. Generally, the push method cannot be used successfully in soils other than soft and medium soft clays and silts.

Coring: This method is employed when refusal is encountered with ordinary drilling techniques. Diamond drilling is used to obtain small diameter samples to determine the nature and extent of hard strata.

Diamond drilling is standardized in ASTM-D2113. The sampler consists of a core barrel with a diamond tipped bit. The core barrel and bit are rotated while water is pumped down the drill rod and out the bit. The sample is retained in the barrel while the circulating water carries the cuttings to the surface.

A general method by which the quality of the rock at a site is related to the amount of fracturing and alteration is known as the rock quality designation (RQD). The procedure consists of summing the total length of core recovered by counting only those pieces of hard and sound core which are 4 inches (.102 m) or greater in length. The ratio of this modified core recovery length to the total core run is known as the RQD.

Rock Quality Designation

RQD	Rock Quality
0-25	Very Poor
25-50	Poor
50-75	Fair
75-90	Good
90-100	Excellent

Special Methods: Many special methods of drilling have been devised, and many of these involve the driving of casing or probes. It is felt that these various methods are too numerous for inclusion in the discussions given in this Manual; however, those interested in further information should see the Bibliography.

The most important factor to consider in soil sampling is to maintain a water level in the casing at or above the existing groundwater table at the location of the boring. When the water level in the casing drops below the existing groundwater, a quick or "running" condition develops. The blow counts obtained in this material are of no value and samples are of questionable quality. A "running" condition is created by drillers' procedures in the majority of the cases; where it is encountered, the data may not be reliable.

SAMPLING: In order to complete an adequate program of bridge foundation exploration, it is necessary to obtain samples for the identification and classification of soil and rock and undisturbed samples for the various field and laboratory tests. If the samples are not truly representative of the materials encountered, erroneous conclusions obviously can be drawn.

Disturbed samples are those in which the soil structure has not been maintained, and they are used for general observation, inspection, soil classification, and in those laboratory tests in which structure is not important. On the other hand, relatively undisturbed samples are used for classification tests as well as density and moisture content determinations, triaxial shear or unconfined compression tests, and consolidation tests. The degree of disturbance depends upon several factors such as type of materials being sampled, core barrel or sampler used, drilling equipment used, and driller skill. Extended exposure of the soil material to the atmosphere will change a relatively undisturbed sample into an unusable state; therefore, the method of obtaining and maintaining representative samples cannot be overemphasized. Although the use of rotary drills or auger drills does not permit in-place visual inspection of the foundation materials, adequate representative and undisturbed samples may be obtained provided that the correct sampling tools, equipment, and procedures are used.

The use of some dynamic field test such as the Driven Penetrometer Test or the Standard Penetration Test should be used in conjunction with the sampling procedure. Good bridge foundation exploration data can be obtained by performing penetrometer tests, and these tests may be used to justify the obtaining of undisturbed samples for laboratory testing. This is important especially when the use of friction piling or spread footings is being considered.

It is to be noted that the Standard Penetration Test or any driven Cone Penetrometer Test is reliable in sand, while in clays dynamic tests are less reliable than in sand. Therefore, with clay and plastic silts the results of laboratory or field tests of undisturbed samples must be relied upon.

Local, empirical relationships of penetration values to pile penetration lengths and soil bearing values have been developed by some organizations by careful correlation studies.

The in-place vane shear test is a valuable tool in determining the in-place shear strengths of clays and silts, and it may be used in conjunction with the sampling procedure.

Split-Barrel Sampling: A split-barrel or split-spoon sampler is used in making the Standard Penetration Test (AASHTO Designation T 206. See APPENDIX E — SAMPLING). The sample obtained from the use of this barrel and test is not an undisturbed one, but it does retain some of the

soil structure. The sample is suited for visual inspection and soil classification, and a portion of it is usually retained in a moisture-proof jar for later reference or possible laboratory tests.

Split-barrel samplers are available in several sizes. The most common size is that specified in AASHTO T 206. When the barrel is laid open, the logger can view in effect a subsurface section equal to the sample length. The split-barrel sample may be used in laboratory tests for moisture content, Atterburg limits, specific gravity, and gradation. When the sample is used for moisture content determinations, the sample jars should be carefully sealed and protected from moisture loss, freezing, etc.

Push Barrel or Thin-Walled Tube Sampling: Push barrel or thin-walled tube (Shelby) sampling is used in obtaining relatively undisturbed soil samples for field and laboratory tests and for soil classification (AASHTO Designation T 207. See APPENDIX E — SAMPLING). This sampler recovers acceptable “undisturbed” sample cores of from 2 to 5 inches (50.8 to 127 mm) in diameter where it is adaptable, but its usefulness is limited to materials into which it can be forced and which have sufficient cohesion to remain in the barrel while the sampler is being withdrawn from the hole. The taking of these samples is facilitated by use of a piston sampler, which allows the influence of a vacuum effect to aid in recovering samples with moderately low cohesion.

When a field laboratory is used, the sample should be tested immediately after it is brought to the surface. The extraction from the tube may be done by forcing the entire sample out of the tube with hydraulic pressure from the pump on the drilling machine, or the sampler may be sawed into short lengths and their contents extruded with a sample ejector. Common tests performed on such samples in a portable field laboratory are unconfined compression, miniature vane shear, moisture content, and Atterburg limits.

When the sample is to be sent to a laboratory for testing, it should be sealed, properly labeled, and stored in a protective place. See APPENDIX E — SAMPLING.

Wet Barrel or Double Wall Sampling: Wet barrel or double wall sampling is used in a wide range of formations when core samples are required for field or laboratory tests and for classification. This sampler recovers cores having diameters of from 13/16 inch to 2-1/8 inches (20.6 to 54 mm) in rock and from 2 to 5 inches (50.8 to 127 mm) in soil. Common sampler barrel lengths are 30 inches to 5 feet (.762 to 1.524 m) for use in soils and 5 feet to 10 feet (1.524 to 3.048 m) for use in rock. This type of sampler is designed with an inner and outer barrel, and circulating water or drilling mud is used.

There are several versions of the double wall sampler; the design depends upon the characteristics of the material to be sampled. For formations other than rock, a type sampler having a thin sheet metal liner fitting the inner core barrel may be used. This furnishes a handy method of removing the core, and it offers a means of protection to the undisturbed core

for transportation to the laboratory. The thin liner is removed from the sampler and preserved as noted in APPENDIX E — SAMPLING.

For rocks and hard shales, the liner is omitted as this type of material has ample strength for handling without the protection of the liner. Some rocks such as soft limestones and soft shales should have a portion of the core sealed in a moisture-proof container since their strength may change upon drying.

Dry Barrel or Single Wall Sampling: Dry barrel or single wall sampling is one method used to obtain samples for visual soil and rock classification and for logging purposes. The core sample obtained is generally in a disturbed condition due to the drill pressure applied when cutting and packing it into the barrel for recovery. The sample is extracted from the barrel with hydraulic pressure from the pump on the drilling machine or by water pressure from the mud pump.

In general, double wall sampling is superior and in most cases yields better results than single wall. Single wall samplers will produce good core recovery only in certain rock types and in the hands of an expert driller.

When the dry barrel is used for sampling in practically all foundation materials encountered except very soft clays (mucks) and cohesionless sands, it will obtain a sample containing all components in the original formation. The amount and degree of disturbance will depend upon the consistency and/or density of the material. Although this method is called the dry barrel method, circulation of drilling fluid is used at all times except when the core barrel is rotated at high speeds and increased downward pressures to shear the core at the bottom of the hole. In hard formations, a smaller volume of water is circulated during the cutting of the core. In competent formations, a relatively "undisturbed" sample is obtained.

Wash Sampling: Although there are many methods of penetrating soils, only those methods which offer an opportunity for sampling and testing the foundation materials without excessive disturbance are recommended. Since wash sampling is merely the obtaining of mixed and highly disturbed samples from the drilling fluid, it should not be used except as a last resort. Classifying a boring solely on the basis of wash samples often leads to erroneous conclusions. It is useful to watch wash water to identify strata changes that may not be picked up in the sampler.

Retractable Plug Sampling: Retractable plug sampling is used to obtain disturbed soil samples for field and laboratory tests and for soil classification. This sampler may be used in an uncased hole, and it is satisfactory for determining the vertical sequence of fine-grained soils.

Generally, samples are obtained in increments not exceeding 3 feet (.914 m). The equipment and procedures of this method as well as for those others listed above are discussed in greater detail in APPENDIX E — SAMPLING.

This sampling method is closely allied with the method of drilling by the taking of continuous samples. The main differences are that in this



method a sampling barrel is used, and also the hole may be advanced without taking a sample. The use of this barrel may be resorted to when difficulty is encountered while using other samplers.

Sample Protection and Transportation: Samples of soil and rock are collected for testing to determine their engineering properties. After the sample has been obtained, it is important to protect it.

When packaging and transporting undisturbed soil samples, it should be remembered that they are fragile and that a damaged or disturbed sample is sometimes worse than no sample.

Some practices and procedures are discussed in APPENDIX E — SAMPLING, under PRESERVING SAMPLES.

FIELD TESTS: Field tests should always be made in conjunction with the drilling, coring, and identification of materials. The purpose of these tests is to determine soil properties in-situ. The detailed procedure of field testing is given in APPENDIX C — TESTING. Therefore, the following portion of this Manual will be limited to general remarks on and the significance of the field tests.

Dynamic Field Tests: These types of tests consist of driving either a rod, cone, sampler, casing, or some other device and recording the driving energy required to achieve a pre-determined amount of penetration. These tests are somewhat similar to the use of a dynamic driving formula for the determination of pile bearing capacity, and they have an advantage over a pile formula in that a standard device is driven with a standard energy (the weight of the hammer and the amount of its fall or drop are standard amounts). Another advantage is that the best of the field tests are made stratum by stratum, while in pile driving, the total or sum of the soil resistance is measured from the ground surface.

A dynamic field test roughly measures either the density (if sand) or the consistency (if clay) of the soil. Since the bearing capacities of granular soils vary directly with their densities, these tests (when properly correlated) are an acceptable indication of the bearing capacity of granular soil. The bearing capacity of a clay is dependent upon its consistency to some extent, but moisture and pore pressures play such a vital role in the bearing capacity of clay that dynamic field tests are less reliable when applied to the bearing capacity of clay.

Standard Penetration Test (SPT): This test is the most widely used of the dynamic field tests, and this Manual recommends its use. Unfortunately, there is more than one test called by this name. All such tests utilize a drop hammer to drive a split-barrel sampler, with the number of blows required to drive the sampler 12 inches (.305 m) being designated the Standard Penetration Count or Blow Count. This count also may be designated by the letter N.

The various tests use different hammer weights, heights of fall, and dimensions of sampling barrel. For the sake of standardization, this

PART III — FOUNDATION EXPLORATION

FIELD TESTS

Manual endorses the test procedure outlined in AASHTO Designation T 206.

This test procedure provides for the driving of a 1-3/8 inch (35 mm) I. D. by 2 inch (50.8 mm) O. D. split-barrel sampler with a 140 pound (63.56 kg) hammer falling 30 inches (.762 m). The blow count is recorded for each of three 6 inch (.152 m) increments, with the sum of the second and third increments being N, or the Standard Penetration Count.

The key to its use is its correlation with soil properties. Many people have worked on this problem, and some have developed footing and pile bearing charts and formulae based upon the SPT.

The split-barrel driven in the SPT gives a sample which is used in logging the hole and in some laboratory tests (see Split-Barrel Sampling in this Part of the Manual). The frequency of testing should follow some standard of practice as has been recommended in the SUB-SURFACE EXPLORATION PLAN in this Part of the Manual.

The results of the test may be used to describe granular soil density and clayey soil consistency as shown in the accompanying tabulation:

<u>GRANULAR SOIL</u>		<u>CLAY</u>	
<u>Blows*</u>	<u>Density</u>	<u>Blows*</u>	<u>Consistency</u>
0 - 4	Very Loose	0 - 1	Very Soft
5 - 10	Loose	2 - 4	Soft
11 - 24	Medium Dense	5 - 8	Medium Stiff
25 - 50	Dense	9 - 15	Stiff
Over 50	Very Dense	16 - 30	Very Stiff
		31 - 60	Hard
		Over 60	Very Hard

The use of a density description does not preclude the need for reporting the actual blow counts.

Cone Penetrometer Test: This test may also be known to some as the Driven Penetrometer Test. It is similar to the SPT, except that a cone is driven instead of a split-barrel, and no sample is recovered. One other difference is that an accumulated skin friction or drag is created on the sampler used in the SPT, whereas no drag is created on the cone.

*Blows shown are for the test procedures given in AASHTO Designation T 206.

In this test, a cone of given diameter attached to the drill stem is driven by a hammer of known weight and which is dropped a regulated distance. These dimensions and weights may vary from organization to organization. One Highway Department uses a 3 inch (76.2 mm) diameter cone with a 170 pound (77.18 kg) hammer which is dropped 2 feet (.610 m).

The number of blows of the hammer for the first and second 6 inches (.152 m) of penetration is significant in indicating the general type of material, i.e., if granular, the number is significantly greater for the second 6 inches (.152 m) than for the first 6 inches (.152 m). If the material is clay, the number of blows for each increment is about the same. Additional details are given in APPENDIX C — TESTING, but as with all forms of dynamic testing, it should be remembered that test values depend upon correlation with other things and with previous work.

Driven Probe Test: This test may prove helpful when it is used in conjunction with or as a supplement to test borings in areas where foundation conditions are believed or known to be erratic. It is not recommended for use alone, but it can be useful in locating bedrock accurately and in determining pile lengths when correlated with known foundation conditions.

There are other versions of this test being used whereby a 2-1/4 inch (57.2 mm) cone penetrometer is driven continuously to refusal with a McKiernan-Terry No. 2 air hammer. By correlation, the data obtained are used to determine how actual piling would drive dynamically.

This test may be known to some as the Probe Point Penetrometer Test.

Driven Casing Test: When casing is driven during a test boring procedure, the number of blows per foot (m) should be recorded. As with the driven probe test, this information may be helpful when used in conjunction with other data, but it is not recommended for use alone.

Static Penetrometer Test: The static cone penetrometer or CPT (cone penetration testing) has been used extensively in Europe for many years, however, it is just gaining popularity in the United States.

The CPT most widely used in the U.S. is the Dutch Cone. The standard Dutch Cone, known as the Begemann Cone, has an apex angle of 60° and projected end area of 1000 square mm. The cone is available in 10 or 20 ton capacities to measure side friction on the penetrometer.

The penetrometer is pushed into the soil by means of the hydraulic feed of a drill rig at the rate of 10 to 20 mm per second. A double set of rods consisting of an outer casing rod and an inner rod that is connected to the cone is required to operate the penetrometer. To measure the point resistance

the outer rod is held stationary and the inner rod is pushed 40 mm, driving the penetrometer into the soil. The force required to push the point is measured by a load measuring device. When a friction sleeve is used, the rod is pushed an additional 40 mm to obtain measurements of both the cone and friction resistance. The sleeve resistance can be found by subtracting the cone resistance from the combined cone and sleeve resistance. After the push is complete, the outer rod is advanced until the penetrometer is retracted to its original position. The distance between soundings is usually 200 mm, but a continuous log can be recorded.

In-Place Vane Shear Test: This test can be performed to obtain the in-place shear strength values of weak, fine-grained soils where the other soil shear tests such as triaxial shear, unconfined compression, and direct shear tests cannot be applied. In general, the test consists of measuring the torque required to fail the cylindrical surface area of soil being sheared by the vanes and converting the data to shearing resistance of soil.

This test is used when silty clays (mucks), clayey silts, and very soft saturated clays are encountered. However, these materials must be free of gravel, large shell particles, and roots in order to avoid inaccurate results and probable damage to the vanes. The test should also be used with extreme caution in soils which require 20 blows per foot (66 blows/m) or higher with the Standard Penetration Test.

Other Field Tests: The tests discussed thus far in this portion entitled FIELD TESTS are those which are made on the soil in-situ. Tests made in field laboratories are virtually the same in procedure as those same tests made in any laboratory, and hence they will be discussed in PART IV — LABORATORY TESTS and in APPENDIX C — TESTING.

This Manual will consider the Miniature Vane Shear Test as one belonging in the latter category.

FIELD BORING LOG: The importance of good logging and field notes cannot be overemphasized, and it is most necessary for the logger to realize that a good field description must be recorded. The field boring log is the major portion of the factual data used in the analysis of foundation conditions.

The log is a record which should contain all of the information obtained from a boring whether or not it may seem important at the time of drilling. It is important to record the maximum amount of accurate information. This record is the "field" boring log, as opposed to the "finished" boring log used in the preparation of the final report made to the designer.

The person who actually logs the field information will vary from organization to organization. Some will have an engineer or trained technician accompany the drill crew, while others may train the drill crew foreman to log the bore hole. In order to obtain the maximum amount of accurate data, the logger

should work closely with the driller and consult with him as to changes in materials and operations while drilling.

Duties of the Logger: Generally, the logger (or note keeper) should be responsible for the following information and/or its recording: Two independent logs are desirable. One kept by the driller and one kept by the Engineer's representative.

1. Description and classification of each rock and soil stratum, and the depth to the top and bottom of each stratum.
2. The depth at which each sample is taken, the type of sample taken, its number, and any loss of samples taken.
3. The depths at which field tests are made and the results of the tests.
4. Information generally required by the log format, such as....
 - Boring number.
 - Date of start and finish of the hole.
 - Name of driller (and of logger, if applicable).
 - Elevation at top of hole.
 - Depth of hole and reason for termination.
 - Diameter of any casing used.
 - Size of hammer and free fall used on casing (if driven).
 - Blows per foot (m) to advance casing (if driven).
 - Description and size of sampler.
 - Size of drive hammer and free fall used on sampler in dynamic field tests.
 - Blow count for each 6 inches (.152 m) to drive sampler. (Sampler should be driven three 6 inch (.152 m) increments or to 100 blow
 - Type of drilling machine used.
 - Type and size of core barrel used.
 - Length of time to drill each core run or foot (m) of core run.
 - Length of each core run and amount of core per run.
 - Recovery of sample in inches (m)
 - Project identification
 - Client
5. Notes regarding any other pertinent information and remarks on miscellaneous conditions encountered, such as....
 - Depth of observed groundwater, elapsed time from completion drilling, conditions under which observations were made, and comparison with the elevation noted during Reconnaissance (if any).
 - Artesian water pressure.
 - Obstructions encountered.
 - Difficulties in drilling (caving, coring boulders, surging or rise of sands in casing, caverns, etc.).
 - Loss of circulating water and addition of extra drilling water.

....Drilling mud and casing as needed and why.
....Odor of recovered sample

6. Any other information the collection of which may be required by policy.

The action of the drill is important and can be of assistance in determining the presence of strata changes, boulders, voids, and other abrupt changes. In cases where a sample is not recovered, the logger can analyze the color of the circulation water and of the cuttings so as to correlate with the previous sample and the following sample.

Field Identification and Classification of Soils and Rocks: Standardization of field classification of soils and bedrocks will be a step forward in the direction of better and more economical bridge foundations. The Unified Soil Classification System, adopted by many state and federal agencies, is recommended by this Manual for use in foundation work. See APPENDIX B — SOILS.

Soil is identified in the field by visual inspection and mechanical tests. It first should be described and then given a classification by the Unified System. In the descriptions, the same soil properties should be used in the same order. One such order could be Soil Density (for granular) or Soil Consistency (for fine-grained); Color; Minor Grain Size; Major Grain Size; and Other Important Facts (Moisture Content, etc.). Two examples of this order of description would be....

....medium dense, red, silty sand (moist).
....Stiff, red, sandy clay (plastic).

Other properties such as grain shape and gradation may be required in the description; however, the important thing is the consistent use of the same order of description each time.

Considering the major soil property of grain size, soil is described either as gravel, sand, clay, or silt. Most soils consist of a mixture of these, and in descriptions, the secondary constituents are considered as modifiers. Except for silt and clay, all soils can be identified by size without much difficulty. The behavior of silt and clay particles overshadows the size of the constituent.

After the soil has been described, its classification by the Unified System is rather simple, as accurate classification by visual inspection only required practice.

When rock is encountered, a procedure or order of description similar to that recommended for soils should be used. Some of the important properties used in rock description are mineral composition, structure, color, and hardness. The common rock name is also given in the description.

Some of the common names are as follows:

Sedimentary	—	shale, limestone, sandstone, dolomite, chalk
Igneous	—	granite, basalt, gabbro, diorite
Metamorphic	—	gneiss, schist, marble, slate, quartzite



Proper classification of the type of rock is based primarily upon experience and a working knowledge of the geology of the area. Identification of rocks is discussed in detail in APPENDIX A — GEOLOGY. A common field identification test is the treating of the sample with acid. Limestones, dolomites, and chinks will have an effervescent reaction.

Field Tests: The use of the different tests previously listed in FIELD TESTS of this Part will vary according to materials encountered and design data needed.

Logging:

Equipment and Supplies: The following items are recommended for the logger's use to aid in obtaining an accurate description of the materials....

- Pocket Knife — To cut samples for testing hardness and for exposing a fresh surface.
- Millimeter Scale — To determine the size of particles if neither size-sampler nor manual illustration is available.
- Size-Sampler — To compare actual sieved and labeled particles of sand, silt, and clay with field samples of unknown size.
- Dilute Hydrochloric Acid — To aid in recognizing calcium carbonate materials such as limestone, chalk, and dolomite.
- Magnifying Glass — To make a better identification of materials by closer inspection (a 10X is recommended).
- Pocket penetrometer and twisting shear device when sampling in cohesive soils.

Format of Field Boring Log: The format of the "field" boring log or drilling report will be based upon organization policy and the information which is desired to be shown, as well as the manner in which it is to be presented. The format should be adequate for recording those items of information previously listed under Duties of the Logger and any special information which may be required by organization policy or by unusual conditions.

It may be desired to show by standard symbols information relative to non-core recovery, core recovery, and the taking of undisturbed samples for laboratory tests. Standard symbols may also be used to indicate the material which has been identified and logged.

Finally, there should be sufficient space for remarks, signatures, and a fully informative heading, which should be filled out as completely as is practical at the site. However, the logger should not be burdened with the recording of repetitive or unnecessary information.

An example of a field log form is included at the end of this Part.

Logging Procedures: Before the boring is started, the logger should first record all preliminary information. Then the different soil strata should be described, identified, classified, and logged as the drilling

and sampling advances, using Standard Penetration samples, Shelby or Push Barrel samples, or Wet or Dry Barrel samples.

Logging should not be done by observing wash return or auger return, although they could be watched for evidence of strata change.

The sampling interval has been discussed previously, but it is to be emphasized that the interval should never exceed 5 feet (1.524 m) for logging purposes. When a sample is taken for classification purposes, the logger should be the one to receive it for examination, identification, description, and classification on the log form. When necessary, he should retain a portion of the sample for further study or laboratory testing, or he may require that an undisturbed sample be taken. When cores are being taken, the logger should discharge them directly from the barrel into the core box or container. Some method of identifying the beginning and ending of each run of the barrel and of the sequence of runs should be used. The depth of the beginning and ending of each run should be noted on each core container, as well as depths of other significant points (voids, strata changes, etc.). In this way, the core and core container will give a picture of subsurface conditions for the length of the core. See APPENDIX E — SAMPLING, PRESERVING SAMPLES.

It is necessary for the logger to determine the depth at which each stratum begins. Strata change and its depth can be accurately determined in sampling provided that samples are taken at close enough intervals. If the change is not detected in the samples, the logger should try to determine the point of change from the drilling return and from discussion with the driller as to how the material drilled.

When rock is encountered, its hardness may be described from a visual inspection of the core, applying terms such as fresh, slightly weathered, or weathered to rocks such as granite, gneiss, and quartzite and terms such as soft or hard to shales, slates, and some limestones. The percentage of core recovery also is an indication of the hardness as well as the continuity of rock — generally, the harder the rock, the higher the core recovery. When considering core recovery, some of the many factors affecting it (aside from the characteristics of the rock itself) and which must be taken into account are the driller's skill, the type of core barrel, and the type of drilling machine being used.

All clay seams, fissures, weathered layers, and other factors and details which are related to the uniformity or continuity of rock are very important and should be recorded on the boring log. Often these things can be determined only by observation while in the field. For example, a clay seam in limestone may not be recovered by the core barrel, but its location and thickness may be determined by observing the progress of the drill tools.

The results of field tests should be carefully recorded on the boring log or on separate forms or sheets in accordance with the organization's policy. With the Standard Penetration Test, this means logging the depth of the test and the number of blows required for each of three 6 inch (152 mm) increments of drive. With the Cone or Driven Penetrometer Test, it means recording the number of blows per increment of penetra-

tion, as well as the depth of the test and the weight and stroke of the hammer used. With the In-Place Vane Shear Test, the test depth, vane size used, rate of application of torque, torque required for initial shear, and the torque required for shear after failure should be recorded.

In every case, the logger should record all pertinent information for which space is provided, as well as giving any additional information which he feels is important.

One rule for the logger to remember about sampling is to not only record the information needed but to bring back portions of all samples retained. And if the logger is not sure of the classification, he should take a sample for laboratory testing and/or review by his superior.

Groundwater Table: In order to determine the elevation of groundwater it is suggested that at least two holes on each location be left open for the duration of the site exploration and periodically checked as to water level. These two holes should have their final check made no earlier than 24 hours after the completion of the boring. The depth to the water level should be recorded on the boring log each time a reading is made, along with the time lapse since completion of the boring. When there is significant difference between the two borings checked, or when the logger deems it otherwise necessary, the water level in other borings should be checked.

Twenty-four hours is generally considered minimal time and if the groundwater table is a critical aspect in the design, readings should be taken at subsequent intervals over an extended period of time and correlated with any available existing groundwater data from U.S.G.S. or other sources to determine the long-term water level stability. Slotted plastic pipes inserted in the bore hole upon completion normally make suitable long-term observation wells.

This record should also indicate which strata are permeable to water and which strata are impermeable to water.

When a rotary or cable tool drill is being used, bailing of the hole will be required. With auger drilling, this is not necessary. Since measuring the depth to the water level is a simple matter, every boring is usually checked.

The location of the groundwater level is an important fact in foundation design, and emphasis should be placed upon proper determination and reporting of this data. A reliable method of recording groundwater is by means of a pipe driven with well points.

The holes should be covered and care taken to prevent any animals, children, etc., from falling into the holes during the observation period.

SITE CLEAN-UP: After the completion of the boring phase, all drill holes should be secured so that there will be no danger of liability to the State. This can be done by backfilling, covering, or sealing. All damaged property such as fences, lawns, etc., should be repaired. All debris and excessive material should be handled to the property owner's satisfaction, and the area should be cleaned up in general.

OPEN PIT AND TRENCH EXPLORATION: Open pit and trench exploration is rarely used now in bridge foundation exploration, and it is usually resorted to only when plate load tests are to be made. The results of these tests provide a good basis for foundation design in granular materials, but these tests are expensive.

Open Test Pits: Open test pits are adapted to use at those sites which are relatively inaccessible to power equipment. The pit depth is limited by the water table, type of material excavated, and the footing elevation (unless located well outside of the footing area).

This type of exploration furnishes an excellent basis for disturbed soil sampling and visual classification. The taking of undisturbed samples for triaxial shear and consolidation tests is tedious and expensive, except in stiff clays.

Excavated materials from each significant stratum can be placed in an orderly manner around the pit and marked with stakes to indicate depths and thicknesses of strata in order to facilitate logging and correlation.

Pits should be cribbed, ventilated, and covered as conditions may require for the safety of the crew, public, and animals.

If the pit is dug in or near the footing area, it should not be carried below the footing level since a significant soil area within the footing will be disturbed and loosened.

Test Trenches: When they are feasible, test trenches can be used to expose soil materials along a given line or section. A dragline, clamshell, back-hoe, or bulldozer is usually utilized for this purpose. This method is best suited for explorations of moderately steep slopes, but it is adaptable to flat ground. The excavation may consist of either a single slot trench down the face of the slope or a series of short trenches spaced at short intervals along the slope.

PART III - FOUNDATION EXPLORATION

		Project		B. H. NO. ①	
Blows per 6 in. penetration of sampler.	Sample No.	Description	Casing Blows	Depth	
71.00	Dry ①	Loose Organic Top Soil	1	1	Start Jan. 5/1963
			2	2	Finish Jan. 6, 1963
		Dry Medium to Fine Sand	3	3	Casing Size 3 1/2"
		Loose Brown Sand	4	4	Hammer Wt. 300#
			5	5	" Fall 24"
			6	6	Spoon Size 2" O.D.
			7	7	" Descr. Silt
		7.5'	40	8	Hammer Wt. 140#
		Medium to Coarse Sand	50	9	" Fall 30"
		Gravel & Cobbles	48	10	Other Samplers Descr.
			60	11	" " " "
		12.0'	38	12	" " " "
		Moist Medium Dense	30	13	Core " Diamond
		Gray Coarse Sand	38	14	" Size 1 1/2"
		Little Medium to Fine	40	15	Drillier Co. A.D.C.
		Gravel Trace Organic	35	16	" Name J. Gish
		Silt	38	17	Equipment Manuf. Acters
		17.0'	70	18	" Model Style A
		Moist Very Dense	85	19	Inspector Gernay
		Brown Fine Sand Some	90	20	
		Silt Cemented	93	21	Remarks
			98	22	
		23.0'	80	23	
		Wet Very Dense Running	160	24	
		Silt and Fine to Medium	110	25	
		Gray Sand Trace of	280	26	
		Mica Boulder @ 25'	120	27	
		25.2'	110	28	
		Boulder 30" Recovery	300	29	
		31.0'	250	30	
		Wet Dense Gray Fine to	130	31	
		Coarse Sand & Gravel	120	32	
			125	33	
			130	34	
		Medium to Coarse Dense	160	35	
		Sand & Gravel	180	36	
		37.0'	200	37	
		Till	300	38	
		Turning Casing 38-40'	400	39	
		40.6' Top of Rock	450	40	
		Core ⑧ Granite Drilling		41	
		Time 40 Min.		42	
		Recovery 52"		43	
				44	
26.00		Bottom of Boring 45.0'		45	

TYPICAL FIELD BORING LOG

No metric equivalents established

PART IV

LABORATORY TESTS

GENERAL: Economical bridge foundation design requires the use of the physical properties of the foundation soil or rock. The physical properties may be determined by insitu tests, load tests and laboratory tests. Laboratory testing is used to predict the foundation behavior based on experience of similar tested soils and their performance in the field. Laboratory testing should be developed by a geotechnical engineer after a review by the Engineer of all samples to ensure the proper and adequate information is obtained for the required facility.

The two reasons for making these laboratory tests are first to verify classification and second to determine engineering properties. When an organization first institutes a foundation investigation program, considerable laboratory testing will be required. However, as experience is gained and correlation between the field work and foundation plans is developed, less laboratory testing will be necessary but an adequate amount of laboratory testing should be conducted to simulate the most severe design criteria. Generally, the amount of laboratory testing performed will depend on the subsurface conditions, laboratory facilities and the type of structure planned.

The engineering properties of soils are determined by such factors as parent material, mineralogical composition, organic matter content, age, method of transportation, place of deposition, method and degree of consolidation, texture, gradation, and structure. Consequently, it is advantageous to classify soils and rocks into groups which exhibit distinct engineering properties, thus enabling engineers engaged in preliminary investigations or in design and construction to facilitate a reliable exchange of information, experience, and data.

Laboratory tests for bridge foundations design will generally fall into three categories: Classification tests, strength tests, and compressibility tests. Other tests may be required such as permeability tests for use in analysis of dewatering systems and compaction tests for control of approach embankments.

Classification tests allow correlation of behavior of similar soils and may minimize the number of detailed tests required. Strength tests are used to predict load carrying capacity of foundations and compressibility tests are used to predict the settlement of the soil-structure system.

Laboratory tests should be selected to give the desired and necessary data as economically as possible. Complicated and expensive tests are justified only if the data will reduce costs or eliminate risk of a costly failure.

Dynamic testing of loose sands may be warranted if liquefaction or excessive settlements due to seismic loads or cyclic mobility are anticipated.

The purpose of this Part of the Manual is to state the significance and place of laboratory tests in foundation exploration work. The details of the tests are taken up in APPENDIX C — TESTING.

GRAIN SIZE, SHAPE, AND GRADATION: Drilling reports and logs of bridge foundation explorations should always contain information on size, shape, and gradation of particles encountered as these properties affect the type and depth of foundation.

of the foundation to be used. For practical purposes, they are reflected in the shear and bearing values for design.

A visual inspection by the drill foreman and possibly by the Engineer in charge of the work is one source of this information; however, it should be corroborated at regular intervals by laboratory tests. It is important to establish whether or not the soil has the characteristics of coarse-grained material (sands and gravels) or of fine-grained material (silts and clays).

Grain size and gradation are established by sieve analysis, hydrometer analysis, and by the elutriation process in some cases. A combined analysis is recommended for general use, utilizing a sieve analysis for determining the gradation of sand and gravel and hydrometer analysis for silt and clay.

In addition to determining the major and minor grain sizes, it is desirable at times to describe the gradation within or even across two grain sizes. For example, a sand with a good distribution of grain sizes from coarse to fine would be described as well-graded, while a sand with all particles near the same size would be considered as uniformly graded. A sand having fine grains and coarse grains but with few or no medium grains is described as being gap-graded. A sand or gravel is also described as to grain size within the category, i.e., coarse sand, fine sand, fine silty sand, coarse gravelly sand, etc. Various grain sizes and gradations are illustrated in APPENDIX B — SOILS.

Typical engineering characteristics of silt and clay do not correspond to particular grain sizes; rather, the two materials are differentiated by their behavior.

The shape of its particles has an influence on the physical properties of a soil. For example, under the same conditions, angular particles have a higher angle of internal friction than rounded ones have. Sands and gravels are described as rounded, subrounded, subangular, and angular as well as by their composition. Particle shape is determined by visual inspection (with the aid of a magnifying glass) and by comparison with a standard. Due to their small sizes, particles of silts and clays cannot be described in a like manner.

Some of the facts which indicate the significance of gradation and grain shape in granular soils (sands and gravels) are as follows...

- Well-graded soils have a higher angle of internal friction and hence a higher bearing capacity than uniformly graded or gap-graded soils.
- Fine-grained soils tend to slough or run more than coarse-grained soils.
- Well-graded soils are less permeable than uniformly graded soils.
- Soils with rounded particles are more permeable than those with angular grain shape.
- Bulky grains are cohesionless and are of such size and nature that the groundwater table becomes of prime importance when spread footings or drilled shafts are being considered.

Samples for the determination of the properties of grain size, shape, and gradation are obtained during the normal foundation exploration program. Standard penetration samples, undisturbed samples, or most disturbed samples are adequate for performing these tests.

SPECIFIC GRAVITY (S.G.): Specific gravity may be defined as the ratio of the weight of the soil particles, exclusive of the voids in the soil, to the weight of an equal volume of water at the stated temperature.

Specific gravity of soil grains is dependent upon the parent materials which form them. The s.g. of these solids is needed in computing the void ratio of a soil mass, percent saturation, consolidation characteristics, and other important soil properties.

The specific gravity itself is of importance as a soil property. For example, organic soils have a low s.g. Also, the presence of barite and other heavy minerals may be deduced from the s.g. of the soil solids.

Standard penetration samples, undisturbed samples, or disturbed samples are adequate for the s.g. test.

ATTERBERG LIMITS: In fine-grained soils, the amount of water present in the voids has a pronounced effect on the soil properties. Three indications or indexes of the effect of moisture, recognized as "Atterberg limits," are the liquid limit (LL), plastic limit (PL), and plasticity index (PI).

The liquid limit is defined as that moisture content at which a soil just ceases to act as a plastic and begins to act as a liquid. The plastic limit is that moisture content at which a soil just ceases to act as a solid material and begins to act as a plastic. It is evident then that the difference between the LL and the PL is the range of moisture contents over which the soil acts as a plastic medium. This range of moisture contents or rather the difference between the LL and the PL is the plasticity index (PI).

Some of the facts which indicate the significance of Atterberg limit tests are as follows. . . .

- Soils which have a liquid limit (LL) in excess of 50 usually are quite compressible.
- Soils which have a high plasticity index (PI) (25+) are sensitive to changes in moisture content.

These Atterberg limits are used as the basis for laboratory differentiation between materials of appreciable plasticity (clays) and slightly plastic or non-plastic materials (silts). These values may be estimated in the field by an experienced soils engineer, but they should be checked by laboratory tests. This information is invaluable in the selection of the proper type and depth of bridge foundation to be used and in anticipating a given reaction to variable moisture conditions.

Standard penetration samples, undisturbed samples, or disturbed samples may be used in laboratory testing for the Atterberg limits.

CONSOLIDATION: This test is used to determine the expected consolidation of material over which a foundation is to be placed. These consolidation characteristics are in turn used to compute the expected settlement of the proposed structure.

Results of consolidation tests are significant only for fine-grained soils (silts and clays).



Since the amount of tolerable settlement is known for most structures, results of these tests may be used in the choice of a safe foundation plan, as well as to evaluate the effect of adjacent fill loads upon a structure.

The use of piles as a foundation system does not preclude the need for consolidation testing. In soft compressible soils, negative skin-friction is an important consideration.

High quality, undisturbed samples are needed for consolidation tests.

TRIAXIAL SHEAR: The triaxial shear test is used to determine the shear strength of a soil for the determination of pile lengths and for determining the bearing capacity for spread footings or drilled shafts. Triaxial shear test results are also needed to give soil design parameters for the design of retaining walls.

High quality, undisturbed samples are needed for triaxial shear tests. Poor samples should be discarded rather than tested, as they will give misleading results.

DIRECT SHEAR: This test is performed sometimes in lieu of other shear tests, and the use of its results is the same as that noted above for the triaxial shear test. It is important to remember that direct shear test results are usually less reliable than those obtained from the triaxial shear test, since the failure line in the direct shear test is imposed by the method of testing, whereas the triaxial method allows the sample to fail in its weakest plane.

On occasions, it is desirable to shear soil or rock along a particular plane. In these cases, a direct shear test may be used.

High quality, undisturbed samples are also needed for this test.

UNCONFINED COMPRESSION: The unconfined compression test of a soil is a uniaxial compression test in which the test specimen is provided with no lateral support while undergoing vertical compression. The test measures the unconfined compressive strength of a cylinder of cohesive or semi-cohesive soil which, indirectly, may be the indicative of the shearing strength.

The test is usually performed upon an undisturbed sample of soil at its natural moisture content. It may also be performed upon a remolded sample to evaluate the consequences of disturbance and remolding upon the shearing strength.

Unconfined compression tests are relatively quick to perform and are usually relatively inexpensive. When used in conjunction with triaxial test, the unconfined compression test is of value and because of ease of performing, it can in cases be used substantially as an index test.

MOISTURE CONTENT AND IN-PLACE DENSITY: Moisture content is defined as the ratio of the weight of water in a soil mass to the weight of the soil solids, expressed in percent. This is a simple, inexpensive but important test when used in conjunction with other test results. Generally, fine-grained soils with a

high moisture content indicate a low bearing capacity and/or high compressibility. The moisture content of fine-grained soils should be compared with the Atterberg limits for these soils in order to reveal the condition of the soils in place. For example, a saturated clay with a moisture content near the liquid limit indicates a soil in the plastic state but one probably having normal consolidation and possibly dangerous characteristics from a settlement standpoint, whereas a clay with a moisture content near or below the plastic limit indicates that it is pre-consolidated and may not be dangerous from a settlement standpoint. Moisture content can be used as a measure of the void ratio of saturated soils when the specific gravity of the solids is known. High moisture content in coarse-grained soils may indicate a high groundwater table which may be troublesome or even prohibit construction of spread footings or drilled shafts.

The in-place density of a soil is simply its unit weight. It may be expressed as total unit weight (weight of water and soil per unit of volume) or as dry unit weight (weight of solids only per unit of volume). The in-place density is used in computations such as void ratio, percent saturation, and the like. Unit weight in itself is a soil property of secondary importance. In coarse-grained soils, high unit weights generally indicate high shear strength and hence high bearing capacity.

Tests for moisture content and in-place density should be performed on undisturbed samples.

CLASSIFICATION: The tests noted here in PART IV are used to describe and classify the soils and rocks used for a bridge foundation. The results of these tests should place a given soil into a group narrow enough so that the engineering properties are known. With these properties known, the proper foundation design can be made.

PART V

COMPILING INFORMATION

GENERAL: Having carried the investigation through the steps of reconnaissance, foundation or site exploration, and laboratory testing, the next step is obviously the compilation of information and the preparation of a report to present to the designer for use in the design of the structure. Additionally, this report will furnish the Resident Engineer with data regarding anticipated construction problems, as well as serving to establish a firm basis for the Contractor to estimate costs, unless the organization's policies or regulations restrict the release of such information. This Manual endorses the policy of releasing such information provided that it is expressly understood the organization will not be liable for any damages or losses incurred as a result of reliance upon it in the bidding or in the construction operations. However, this has not been sufficient in some instances where claims for losses due to misinformation have gone to juries. Therefore, it is important that any information released should be as accurate as possible.

The report should be in graphical, tabular, and written form, and it should contain the location plan of the borings, finished boring logs, soil profiles where required, a summary of field and laboratory test data, and the Soils Engineer's recommendations.

Prior to preparing final logs and as initial stage of analysis, all samples should be checked by the Engineer performing the foundation analysis. This should ideally be performed immediately after the borings are completed and even while the program is still in progress. The samples will be fresh and most representative of their natural conditions. Appropriate samples can be selected for testing. Significant soil characteristics that may have been omitted from the field logs may be identified, and the Engineer thus alerted to a potential foundation problem that might otherwise have gone undetected.

FINISHED BORING LOG: It is important to differentiate clearly between the "Field" Boring Log and the "Finished" Boring Log. The field log is a factual record of events whereas the finished log is a graphical representation. The field log gives a wide range of information in notes or tabular form as is discussed in PART III — FOUNDATION EXPLORATION. The finished log is then drawn from the data given in the field log, as well as from the results of visual inspection of samples. Laboratory test results also are utilized in its preparation, along with information shown on the preliminary bridge plans.

As noted above, the finished log is a graphical picture or drawing of subsurface conditions, and in order to make it more complete, various data should be superimposed upon it. This may include the results of laboratory tests, as well as the following...

- Results of field tests, including the number of blows per foot (.305 m) to advance sampling spoons or barrels and/or penetrometer, using standardized procedures. Where neither AASHTO nor ASTM standard tests are used, the weight in pounds (kg) and the drop in feet (m) of the hammer should be shown. The sampling or testing device, if not standard, should be described.
- The soil strata plotted against elevation, using a convenient vertical scale. (The soil in each stratum should be described and classified.)

- Where rock characteristics are pertinent, RQD, planar features and surface of core breaks, along with other geologic data.
- The groundwater level.
- Sampling elevations.
- Ground surface.
- Footing elevation, if any.
- Boring number.
- Location of boring.
- Date of boring.
- The name of the technician, engineer, or driller in charge at the time the boring was made.
- Terminal point of boring and reason for termination.
- Percent core recovery for each coring run.

Other information which may be shown on the finished log when its use is considered applicable or proper by the Soils Engineer or when policy requires it is the following....

- Elevation of pile cut-off and of estimated pile tip.
- Diameter of any casing used.
- Size of hammer and free fall used on casing (if driven).
- Blows per foot (.305 m) to advance casing (if driven).
- Description and size of sampler.
- Size of drive hammer and free fall used on sampler in dynamic field tests.
- Type of drilling machine used.
- Type of core barrel used.
- Length of time to drill each foot (.305 m) of core run.
- Obstructions encountered.
- Difficulties in drilling (caving, boulders, caverns, hydrostatic uplift or surging, etc.).
- Loss of circulating water and addition of extra drilling water.
- Drilling mud and casing as needed and why.

Some agencies may prefer to make attachments to the finished boring log to show laboratory test results and other data.

The resulting plot represents the soil and rock conditions at the location of the boring, and it gives the designer an opportunity for visual inspections and comparison.

By studying the materials as shown at the boring location and comparing the driving resistances, some idea of the soil conditions may be secured. If it is driven, the resistance of casing will indicate at least relative load-carrying capacity, and the cumulative resistance as shown is sometimes helpful in estimating pile lengths. The driving resistance of the sampler usually gives a better indication than that of the casing.

The log format should be selected in accordance with the data it is desired to show and the method in which it is to be shown, i. e., showing all information on the log or using attached information sheets.

PLOTTING SOIL PROFILES: In many cases, it may be advantageous to plot a soil profile along various longitudinal or transverse lines. This should be done by plotting the borings in their true relation, but with the vertical scale exaggerated,

PART V — COMPILING INFORMATION ARRANGEMENT OF TEST DATA

connecting the similar strata by lines, and shading similar areas by means of an identifying cross-section mark. The groundwater level should also be shown on the plot. Thus a probable representation of the conditions between borings can be given; however, it must be remembered that the borings represent conditions only at specific locations and exactly what lies between them may be subject to various interpretations. The assumption that there is a reasonable and consistent arrangement, although usually true, could be entirely erroneous in any one case and subject the State to legal claims of false representation of engineering data.

Some organizations may also wish to show bridge station numbers, proposed bent locations, footing elevations, and estimated pile tips on the soil profile. Any information like bent locations and especially pile tip elevation must be carefully qualified. Bent and abutment locations are subject to change during design. Pile tip elevation is very dependent upon pile type and design capacity. These latter parameters must be clearly stated or erroneous assumptions may be made.

ARRANGEMENT OF TEST DATA: As noted in PART IV, elaborate laboratory testing is not warranted in each investigation, but when it is necessary, the final report of field and laboratory testing (both classification and performance tests) should contain the following information:

1. Indication of soil tests performed on each soil sample.
2. Natural moisture contents.
3. Unit weight.
4. Graphical plot indicating the trend of natural water contents together with Atterberg limits.
5. Laboratory data pertaining to consolidation and shear tests to be noted at proper elevations.
6. Grain size data to be indicated and logged by percent gravel, sand, silt, and clay, and coefficient of uniformity.
7. Graphical plot of drained or undrained shear strength vs. depth, as obtained from triaxial shear, unconfined compression, direct shear, or vane shear tests. (Triaxial shear test apparatus may be used for many other types of performance tests.)

Often it is helpful to show the results of field and laboratory tests on the finished boring log and thus provide a quick reference to the soil properties of each stratum.

CRITICAL STUDY AND IMPLICATIONS: In general, discrepancies may arise in soil strength data as obtained from field penetration tests, vane shear tests, and laboratory triaxial shear, direct shear, and unconfined compression tests. Explanation of any discrepancies may fall in the following categories and may require the expert knowledge of an experienced soils engineer.

