1 SUBSURFACE EXPLORATIONS AND SAMPLING

JOHN LOWE III Consulting Engineer
PHILIP F. ZACCHEO Staff Consultant, Ebasco Services Incorporated

1.1 INTRODUCTION

The proper design of civil engineering structures requires adequate knowledge of subsurface conditions at the sites of the structures and, when structures are to consist of earth or rockfill materials, of subsurface conditions at possible sources of construction materials. The structures may be divided into three categories.

1. Structures for which the basic problem is the interaction of the structure and the surrounding ground. Such structures include foundations, retaining walls, bulkheads, tunnel linings, and buried pipes. The main point of interest is the load-deflection characteristics of the interface.

2. Structures constructed of earth such as highway fills, earth and rockfill dams, bases and subbases for pavements, and backfill behind retaining walls. Besides the interaction of the earth structure with the adjacent ground, properties of the construction materials are required for determining the action of the earth structure itself.

3. Structures of natural earth and rock as natural slopes and cut slopes. In this case, knowledge of the properties of the natural materials is required.

In order to perform this design work properly, the engineer must have a good understanding of the problems encountered in making subsurface explorations and of the various tools available to make subsurface explorations. Specialists in soil and rock engineering and/or geology are required for planning, conducting, and supervising the programs of subsurface explorations.

The types of subsurface information required for design include, but are not limited to, the following:

1. Areal extent, depth, and thickness of each identifiable soil stratum, within a limited depth dependent on the size and nature of the structure, together with a description of the soil including its degree of density if cohesionless and degree of stiffness if cohesive.

2. Depth to top of rock and the character of the rock, including such items as lithology, areal extent, depth, and thickness of each stratum; strike, dip, and spacing of joints and bedding planes; presence of fault and shear zones; and state of weathering or decomposition.

3. Location of groundwater and the presence and magnitude of artesian pressures.

4. Engineering properties of the soil and/or rock in situ such as permeability, compressibility, and shear strength.

The procedures for obtaining subsurface information may be divided into the two broad categories of indirect and direct methods. Indirect methods include: aerial photography and topographic map interpretation, and the use of existing geological reports, maps, and soil surveys.

Direct methods comprise the following:

1. Geologic field reconnaissance, including the examination of in situ materials in natural and man-made exposures such as river banks, escarpments, highway and railway cuts, quarries, and existing shafts and tunnels.

2. Soundings and probings.

3. Borings, test pits, trenches, shafts, and adits from which representative disturbed and/or undisturbed samples of the in situ materials may be obtained.

4. Simple field tests, such as the Standard Penetration Test (SPT) and the static cone penetration test, whose results have been correlated with engineering properties on a general basis.

5. Field tests such as the vane shear dilatometer and pressure-meter tests, seepage and water-pressure tests, plate bearing tests, the CBR test, and pile load tests, wherein the engineering properties of the in situ materials are measured directly.

It is the purpose of this chapter to present essential information for the complete range of subsurface explorations. Included are descriptions of the planning of an exploration program; indirect methods of exploration; drilling equipment and techniques; sampling equipment and techniques; field test procedures; and suggestions for reporting subsurface exploration information. A list of references is given at the end of the chapter.

1.2 PLANNING AN EXPLORATION PROGRAM

1.2.1 Purpose of Explorations and Phased Execution

The basic purpose of an exploration program is to provide the engineer with a knowledge of the subsurface conditions at the site of an engineering project. Normally, the explorations provide information required for the safe and economical design of a project and inform the construction engineer about the materials and conditions he will encounter in the field. At times, the explorations may be used to obtain information for the analysis of the failure of an engineering structure.

Explorations are normally accomplished in a phased sequence as follows:

1. Reconnaissance investigations

2. Explorations for preliminary design

3. Explorations for detailed design

4. Explorations during construction
Each phase of explorations together with the engineering done in that phase discloses problems that require further investigation in the next phase. Not all phases are required on all projects; the fourth phase generally is not necessary.

The number, type, location, size, and depth of the explorations are dependent upon the nature and size of the project and on the degree of complexity and critical nature of the subsurface conditions. A general rule of thumb is that the cost of the subsurface explorations for design should be in the range of 0.5 to 1.0 percent of the construction cost of the project. The lower percentage is for large projects and for projects with less-critical subsurface conditions; the higher percentage is for smaller projects and for projects with critical subsurface conditions. About half the cost would be expended for explorations for preliminary design and about half for detailed design. A very much smaller amount of money would be expended for explorations in the reconnaissance investigation phase. No rule of thumb can be given for the cost of explorations during construction. Such explorations are used to investigate special problems that may arise during construction or to better delineate the materials in borrow areas or quarries in connection with the contractor’s scheduling of his operations. Generally they are not required but, when used, their cost can vary widely from one project to another.

The combined cost of planning the subsurface explorations, supervising the explorations, laboratory testing, and reporting the results usually amounts to about the same cost as the explorations. In general, it is justifiable to spend additional money on explorations and related testing and engineering as long as the savings that can be effected in the project construction cost on the basis of the information obtained are significantly greater than the cost of the explorations plus related engineering work.

Local building codes often specify the minimum number of borings required for a given size and type of structure. In the case of a lightweight structure that is to be founded in an area of relatively uniform subsurface conditions, this minimum number of borings generally will suffice and all borings may be completed during a single exploration program.

At times, because of deadlines set for completion for the engineering work, the argument is given that since the information from a full and proper exploration program will not be available in time for use in the design, the exploration program should be cut. In such cases, the much-preferred procedure is to proceed with the engineering on the basis of the best assumptions that can be made from the available subsurface information, but to continue with the full and proper program of explorations and testing. The information obtained will then either confirm the assumptions made to complete the engineering on time or indicate where changes in the design assumptions have to be made. Frequently, any modifications required by the changes indicated by the full exploration program can be made without undue difficulty and in a timely manner.

The sequence in which the explorations are to be performed is often left to the discretion of the drilling contractor. In such instances, the sequence will be governed by the ease of operation for the driller. Movement of the rigs between borings will be kept to a minimum; all borings in one area of the site may be drilled before those in another area are started. Often it is not only advantageous but essential that the engineer designate the sequence of the explorations. If, for instance, the borings being drilled are intended to fill gaps in a geologic profile based on previous explorations, the information from a given boring could preclude the need for one or more other borings that had been programmed. The sequence may also be dictated by time limitations if the time available for design is short. It is not unusual for project design and laboratory testing to be concurrent with the explorations. Under these conditions, it may be necessary to obtain samples first from specific areas in order that testing may progress in a timely fashion.

1.2.2 Type and Number of Drilling Rigs

The types of rigs used will depend primarily on the type, size, and depth of the explorations; the location of the explorations, that is, whether they are onshore or offshore; the accessibility of the area to be explored; the types of rigs available in the area; and the terrain or sea conditions. The types of rigs used for exploration work and their applicability to various conditions are discussed in a subsequent section. The minimum number of rigs required to perform an exploration program is dependent on the time available for the execution of the program, the rate of advancement of the holes by the selected rigs, and the sequence of explorations. The estimated rate of advancement of the hole should include time allowances for equipment breakdowns, movement of the rigs from one location to another, and standby due to weather.

1.2.3 Types of Sampling Equipment

The sampling equipment to be used will depend on the type of information required and the characteristics of the materials to be sampled. If only classification of the soil strata is required, disturbed samples will suffice and samplers such as the split-tube drive sampler may be used. If, on the other hand, the ultimate goal is the determination of the engineering properties of the soils by laboratory testing, more sophisticated equipment such as the thin-wall tube and double-tube core barrel samplers will be required. The sizes and types of samplers will depend also upon such factors as the presence or absence of gravel; the maximum size of particle to be sampled; the type of material to be sampled, that is, cohesionless or cohesive; the density of cohesionless materials; the consistency of cohesive materials; and the location of the material to be sampled with reference to the groundwater level. The types of samplers available and the specific conditions under which each may be used are discussed in detail in the paragraphs on samplers and sampling techniques.

1.3 RECONNAISSANCE INVESTIGATIONS

1.3.1 Purpose and Scope

The reconnaissance investigations provide information for prefeasibility studies and for planning the explorations for the succeeding phase, explorations for preliminary design. This program, for a localized project such as a building that is to be constructed on a preselected site, will be somewhat limited in scope. However, when a dam or highway project is under consideration, several alternative sites or alignments must be considered. The information obtained in this phase aids in the selection of the alternative sites or alignments for investigation. A large portion of the work during this phase falls into the category of research. Also included would be field reconnaissance by a geologist and a soils engineer plus such geophysical explorations and borings as are deemed essential.

1.3.2 Research

Any investigation begins with a thorough search for all existing information that could shed light on subsurface conditions at