Overview of Geotechnical Investigation

1. Introduction

Soil investigation is a very important step for any civil engineering project. It allows identifying potential problems that may arise during the study of a construction project or during the assessment of damages. Understanding the properties of a site provides the link between the cause of a damage and the solutions proposed to address it.

In summary, there are **two main categories of soil investigation methods** that complement surface geological surveys:

- **Observation methods of the site**, either directly in the field or using samples (extending surface geology to depth), such as: wells, trenches, and borings.
- **In-situ measurement methods**, based on measuring a physical property of the soil, including geophysical tests.

Geological reconnaissance involves identifying the soil by visually observing the different layers, confirmed through geological maps. This is done by examining wells, tunnels, or trenches, which generally provide a "fresh" cross-section of the soil. Existing cavities can also be used. Examining nearby quarries or trenches provides immediate details about sub-layers. Reconnaissance can also be performed using borings, which allow establishing preliminary cross-sections or even block diagrams that can be confirmed by further boreholes.

On the other hand, **geophysical investigation methods** allow determining the nature of deep layers by analyzing their properties using in-situ geophysical tests, such as magnetic, electrical, seismic, or gravimetric methods.

Moreover, for greater accuracy, **geotechnical investigation of the subsoil** is the most important. It is based on:

- **In-situ tests**: dynamic and static penetration tests, pressiometer tests, etc.
- **Laboratory tests**: natural moisture content, particle size analysis, Atterberg limits, shear tests, compaction tests, oedometer tests, etc.

All of this is summarized in a **final geotechnical report**, which specifies the foundation system to be adopted and provides recommendations regarding potential instability risks.

2. Objective of the Investigation

The objective of a soil study carried out prior to a construction project (geotechnical study noted: **G12**) is to determine the **allowable stress or bearing capacity** of the subsoil of the site.

The results of the soil investigation are presented in a **geotechnical report**, which specifies the technical feasibility of slabs and earthworks for the construction project. The report clearly indicates the **foundation bearing level (depth)** that must be strictly respected by the contractor.

In other words, the aim is to determine the **physical, mechanical, and hydraulic properties** (compressibility, strength, and permeability) of the in-place soils and rock, as well as the **groundwater level**, for the design and construction of the planned structures.

A geotechnical study and soil/rock investigation include:

- Carrying out **boreholes** to obtain disturbed and undisturbed samples for laboratory testing
- Performing **in-situ tests**
- Installing **piezometers** to determine the groundwater level
- Conducting additional measurements to obtain maximum geotechnical information for design and construction

These data are necessary to:

- Identify the nature of the subsoil
- Determine the mechanical characteristics of the ground
- Define or verify certain soil properties such as:
    - Shear strength
    - Bearing capacity
    - Settlement
    - Permeability

All of this is related to the design and construction of the planned structure.

Finally, any geotechnical report must necessarily include the following information:

- **Factual data:** (location of boreholes, borehole reports, groundwater level, results of laboratory and in-situ tests, etc.);

- **Interpreted (non-factual) data:** (soil stratigraphy between samples from the same borehole or drilling, soil stratigraphy between different boreholes, physical and mechanical soil properties used for calculations);
- **Professional opinions** based on the interpretation of the obtained geotechnical data related to the purpose of the study. These opinions may concern the following aspects, depending on the geotechnical study: (Excavability of soils or rock, Water inflow into excavations, Stability of excavation bottoms or bearing capacity of excavation soils, Allowable bearing capacity of foundation soils, Settlement of foundation soils due to loads from proposed footings, Choice of foundation type, Suggested types of piles, if needed, Soil improvement techniques, Temporary support methods for excavations, Drainage methods, Pavement design, Design of paved surfaces, Interaction of the proposed works with existing structures)

A geotechnical study may include some or all of the following elements: investigation through boreholes and in-situ tests, trial pits with sampling and vane shear tests for clay deposits, pressuremeter tests, geophysical investigations, observation of the groundwater level, description and classification of samples, laboratory testing on samples, environmental characterization if necessary, and finally calculations.

The geotechnical study gathers all available information about the site (geological maps, soil maps, aerial photographs, and existing soil studies from nearby sites). A site visit, carried out to prepare the geotechnical proposal, allows observation of the general conditions of the site (topography, outcrops, presence of obstacles, trees, fill materials, and structures, etc.) and provides information about the behavior of existing structures.

3. Different Stages of a Geotechnical Investigation Campaign:

During the execution of a geotechnical project, every constructor must take into account the nature of the formations that make up the subsoil of the site where the development is planned. This consideration allows the project to be adapted to the specific site, defines the foundation system of the structure with the best safety/cost ratio, and ensures protection against the effects of construction on neighboring buildings.

3.1 Complementarity between the Geotechnical Engineer and Other Earth Science Specialists:

For reasons of expertise, the responsibility for issues related to the subsoil formations is assigned to specialists, the geotechnical engineers, whose mission generally covers

several points in collaboration with other specialists such as geologists, hydrologists, hydrogeologists, surveyors, and geophysicists. These tasks include:

- Defining the general geological, hydrogeological, and topographical framework of the studied site while considering the surroundings of the project;
- Identifying existing natural hazards, such as detection of cavities, overall site stability (for example, regarding landslides), and seismicity;
- Defining excavation works: feasibility, reuse of materials, stability of slopes and excavation walls;
- Assessing the influence of groundwater flows and the aggressiveness of water on concrete;
- Determining the influence of the nature and distribution of geological formations on the execution of works and the design of the structure, including evaluation of the loads these formations can sustain, selection of foundation types, and assessment of settlements under the structures;
- Assessing the impact on the surrounding environment of the project, including slope stability, neighboring constructions, and nuisances related to future works.

3.2 Main Missions of the Geotechnical Engineer

To carry out these missions, the intervention of the geotechnical engineer is generally divided into two main parts:

- **Investigation phase on the studied site:** This phase aims to obtain information about the formations that make up the subsoil (homogeneity or heterogeneity of the subsoil, determination of the geo-mechanical characteristics of the formations, presence of groundwater flows, etc.). Various methods can be used to gather this information, including visual geological reconnaissance, in-situ mechanical tests (destructive drilling with or without pressuremeter tests, cored drilling, penetrometer tests, etc.), and geotechnical laboratory tests on materials sampled from the site.
- **Engineering phase:** This phase involves analyzing the investigation results, synthesizing them to retain only the representative and important parameters, modeling the behavior of the future development on the proposed site using these parameters, and studying the feasibility of technical solutions that allow the specific adaptation of the development to its site.

Consequently, **the geotechnical engineer** often summarizes their mission (investigation + engineering) in **a geotechnical study report**, which corresponds to a clearly defined mission (a “contract” between the client and the engineer). The report

aims to present to the constructors the framework in which they will carry out their development (project environment, subsoil geology, groundwater, etc.) as well as practical, viable, and economical technical solutions to ensure the project is executed safely and at minimal cost.

In France, **the NF P 94-500 standard** is the reference document defining **the regulatory framework for the geotechnical engineer's work**. It defines several types of geotechnical missions, allowing the engineer to adapt their intervention depending on the project's level of progress and the goal of the study. These missions are summarized as follows:

A. First phase: Reserved for other specialists, such as geologists, hydrologists, hydrogeologists, surveyors, and geophysicists.

B. Second phase: Entrusted to a geotechnical engineer according to **NF P 94-500 (2006) (G1 to G5)**:

- **G1:** Preliminary geotechnical study (preliminary & schematic design, APS)
- **G2:** Geotechnical design study (geotechnical study of the final design, APD)
- **G3:** Geotechnical construction study (study and geotechnical execution monitoring)
- **G4:** Geotechnical execution supervision (geotechnical supervision of construction)
- **G5:** Geotechnical diagnosis

4. Overview of Standard Geotechnical Missions (NF P 94-500 Standard)

4.1 Step 1: Preliminary Geotechnical Studies (G1)

These missions exclude any consideration of quantities, execution timeframes, and costs of geotechnical works, which fall within the scope of a geotechnical project study (Step 2). They are normally the responsibility of the project owner.

4.1.1 Preliminary Site Geotechnical Study (G11)

This study is carried out at the preliminary stage and allows an initial identification of the geological risks of a site. It consists of:

- Conducting a documentary review of the specific geotechnical context of the site and the presence of nearby structures;
- Defining a specific geotechnical investigation program, carrying it out or ensuring its technical supervision, and interpreting the results;
- Providing a report including a preliminary geological model, general principles for adapting the project to the site, and an initial identification of risks.

4.1.2 Geotechnical Preliminary Design Study (G12)

This study is carried out at the preliminary design stage and aims to reduce the consequences of major identified geological risks. It consists of :

- Defining a specific geotechnical investigation program, carrying it out or ensuring its technical supervision, and interpreting the results;
- Providing a report outlining the geotechnical assumptions to be considered at the preliminary design stage, along with general construction principles (particularly regarding earthworks, retaining structures, foundations, risks of ground deformation, and general provisions concerning groundwater and surrounding structures).

4.2 Step 2: Detailed Preliminary Design Geotechnical Study (APD), (G2)

This study is carried out to define the design of geotechnical structures and aims to reduce the consequences of significant identified geological risks. It is generally the responsibility of the project owner and may be integrated into the overall project management mission. It is structured as follows:

Project Phase:

- Define a specific geotechnical investigation program, carry it out or ensure its technical supervision, and interpret the results;
- Provide an updated synthesis of the site along with technical notes describing the proposed execution methods for geotechnical works (particularly earthworks, retaining structures, foundations, provisions regarding groundwater and surrounding structures), as well as associated threshold values and certain design calculation notes at the project level;
- Provide an estimate of quantities, timeframes, and execution costs for these geotechnical works, and identify the consequences of residual geological risks.

Construction Contract Assistance Phase:

- Prepare the documents required for contractor consultation for the execution of geotechnical works (drawings, technical specifications, bill of quantities and cost estimates, preliminary schedule);
- Assist the client in the selection of contractors and in the technical analysis of the submitted bids.

4.3 Step 3: Execution of Geotechnical Works (G3 and G4, distinct and simultaneous)

4.3.1 Geotechnical Execution Study and Monitoring (G3)

Carried out in two interactive and inseparable phases (study and monitoring phases), this stage helps reduce residual risks through the timely implementation of adaptation or optimization measures. It is generally assigned to the contractor.

Study Phase:

- Define a specific geotechnical investigation program, carry it out or ensure its technical supervision, and interpret the results;
- Study the geotechnical works in detail, including validation of geotechnical assumptions, design and sizing (justification calculations), execution methods and conditions (phasing, monitoring, controls, instrumentation based on associated threshold values, and possible additional construction provisions), and prepare the geotechnical execution file.

Monitoring Phase:

- Monitor the instrumentation program and the execution of geotechnical works, and, if necessary, implement the predefined construction measures established during the study phase;
- Verify geotechnical data through observations during excavations and, if necessary, through additional geotechnical investigations (carried out or technically supervised and interpreted);
- Participate in the preparation of the final construction report and in providing maintenance recommendations for the geotechnical structures.

4.3.2 Geotechnical Supervision of Execution (G4)

This phase ensures that the execution study and monitoring comply with the project objectives. It is generally the responsibility of the project owner.

Execution Study Supervision Phase:

- Provide an opinion on the geotechnical execution study, on potential adaptations or optimizations of the geotechnical works proposed by the contractor, and on the monitoring (instrumentation) program and associated threshold values.

Execution Monitoring Supervision Phase:

- Provide opinions, through occasional site visits, on the geotechnical conditions as observed by the contractor, on the observed behavior of the structure and nearby constructions, and on any proposed adaptations or optimizations of the geotechnical works by the contractor.

4.3.3 Geotechnical Diagnosis (G5)

During the course of a project or throughout the life of a structure, it may be necessary to carry out a limited study focusing on one or more specific geotechnical elements within the framework of a specific mission.

- Define, after a documentary review, a specific geotechnical investigation program, carry it out or ensure its technical supervision, and interpret the results;
- Study one or more specific geotechnical elements (for example: retaining structures, dewatering, geotechnical causes of a defect) within the framework of this diagnosis, without involving other geotechnical aspects.

If this diagnosis leads to modifications or the execution of works, further geotechnical project and/or execution studies, as well as monitoring and supervision, must be carried out in accordance with the sequence of geotechnical engineering missions.

5. Summary of Standard Geotechnical Missions

The standard missions of the geotechnical engineer (from G1 to G5) are clearly summarized in the flowchart presented below (Figure I.1).

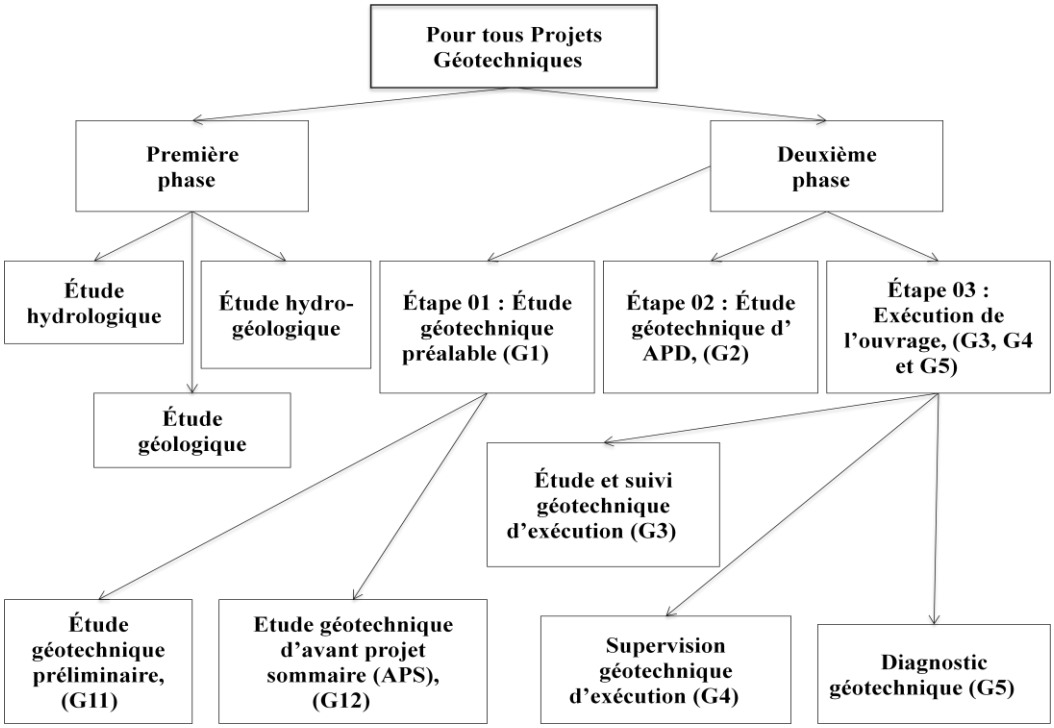

Figure I.1: Classification of Standard Geotechnical Missions (NF P 94-500 Standard)