

# Introduction

In a few years you will be a graduate in Civil Engineering. After acquiring some experience, you may wish to start out on your own. Get a small office, put up a name plate on the door to announce that you are now a Consulting Engineer. We hope that this Book will encourage you to become a Consulting Geotechnical Engineer.

This Book is designed for you.

So is it fair for you to assume that after reading, studying, understanding this Book you will be competent to be a practicing Consulting Geotechnical Engineer? The answer is both yes and no. Yes, because one has to begin some time and yes, you should be able to begin. No, because to continue after beginning, one has to keep growing and that means keep learning.

Learning is a life-long process. Geotechnical Engineering, as a discipline, took birth about 60 years ago. Prof. Karl Terzaghi, who is no longer alive, is credited to be the father of this discipline that began with the name of Soil Mechanics. Soil Mechanics has grown enormously in the last six decades. Today, if you go to the Google search engine on the Internet and seek out pages related to Geotechnical Engineering you will find about 812,000 of them. If you log on to [www.geotechnicaldirectory.com](http://www.geotechnicaldirectory.com) you will be bowled over to see the books, journals, conference proceedings that are published annually and the stock that has accumulated over the last few decades.

This Book is not a very thick one. Clearly it does not have in it all the information and knowledge we now possess about Geotechnical Engineering. If it were double the thickness, it would still not have all the information. For us it would have been marginally easier to write a book with double this thickness because we would have had to spend somewhat less time deciding what to include in the Book and what to leave out. This Book is the size it is because we have attempted to include in it just enough information for you to get started as a Consulting Geotechnical Engineer and also for you to get to know what you don't know. What you don't know, you will be able to seek out when you need to know.

So let us visualize your career as a Consulting Geotechnical Engineer. The name plate is fixed outside your office door and the clients will start knocking at your door. What advice do they seek? What is a Consulting Geotechnical Engineer an expert in?

## A. Areas of Work of the Consulting Geotechnical Engineer

The Consulting Geotechnical Engineer works with soil. He/she is not concerned with the capacity of soil that enables plants to grow in it. His/her concerns originate from the interests of the Civil Engineer. There are four primary areas of work for the Consulting Geotechnical Engineer:

- (i) to predict the behaviour of soil when it is subjected to load in order to be able to determine how much load it can safely carry and when necessary to improve the capacity of soil to withstand load,
- (ii) to be able to retain soil in defined zones and prevent it from intruding into spaces beyond those zones,
- (iii) to estimate how much water will flow through soil and to ensure that it is an acceptable amount, that the flowing water does not carry soil particles with it and thus does not undermine structures that the soil may be supporting, and, that the flowing water does not carry contaminants with it and pollute the surrounding soil and ground water, and
- (iv) to use soil as a construction material to build embankments with it for highways and rail tracks and build *earth dams* with it to impound water and waste products.

Each of these four is considered in turn.

### 1. Load Carrying Capacity of Soil

The earth's surface consists of either soil, or rock or water. Where there is soil or rock, we have learnt to construct roads, bridges, buildings, dams and a variety of other Civil Engineering structures. These structures rest on soil or rock. Even structures constructed in the ocean, rest on or are anchored to the soil or rock that exists at the bottom of the ocean. These structures apply load on soil or rock. They are held in position by being embedded in soil or rock. The Consulting Geotechnical Engineer is concerned with how the soil behaves when it is loaded by these structures. It is the Consulting Geotechnical Engineer's job to make sure that the load that reaches the soil is such that the soil is able to withstand the load in a manner that is safe for the structure. To ensure this, the *superstructure*, that is, the visible part of the structure and the soil are linked with the *sub-structure* that is usually not visible since it is below the ground. The sub-structure is also called the *foundation*. Design of such sub-structures is discussed in Chapter 23.

This area of work of the Consulting Geotechnical Engineer does not get much publicity because no one sees it, unless of course the foundation fails or malfunctions. Every one has heard of the Leaning Tower of Pisa. It is famous because it leans. It leans because the Consulting Geotechnical Engineer designing the foundation for the Tower goofed; the foundation is faulty. Due to the load of any structure, the soil compresses and on account of this, the structure settles. It takes time for the soil to compress and so in some soils the settlement continues to take place for many years. The Leaning Tower of Pisa settled more on one side and less on the opposite subjecting it to a tilt. The Tower has a problem arising out of *differential settlement*. In this area of work, the Consulting Geotechnical Engineer has to estimate settlement, differential settlement as well as the time it will take for the settlement to occur. The property of soil that controls the settlement is known as *Compressibility*; it is discussed in Chapters 8 and 10. The settlement is estimated using *Settlement Analysis* that is discussed in Chapter 19.

The Consulting Geotechnical Engineer also has to ensure that the load reaching the soil will not cause the soil to give way, that is, yield so much that the superstructure is left with no support and it

collapses. When soil is loaded it always yields, only when it is loaded excessively beyond the capacity of the soil to sustain the load does it yield so much as to cause failure. The property of soil that determines the yield is its *Shear Strength*; it is discussed in Chapters 11 and 12. Whether a structure will collapse or not is assessed using *Bearing Capacity Analysis* and that is discussed in Chapter 20.

## 2. Retaining Soil

You must have come across construction workers digging trenches to lay pipes or excavating soil to make room for construction of a basement to be located below the ground floor of a building. The construction worker would feel very frustrated if he/she digs a trench and before he/she has laid the pipe, the trench gets filled up on account of the soil on the sides of the trench slipping into the trench. Similarly, the basement excavation must remain open until the basement is constructed. The unexcavated soil must remain in its place outside of the excavated zone. Another situation, that often makes newspaper headlines, is when the soil on the mountainside slides and blocks highways or destroys whatever it encounters in the valley. The soil moves from its place to a place where it is not wanted. The soil thus has to be retained, supported and stabilized. Sometimes one can achieve this by giving the soil a gentler slope. There are situations when there is no space to make a gentle slope, say, for example, an excavation for a subway along a road that has buildings on either side. One then needs to make vertical or near vertical cuts into soil and support them with *retaining structures*. The design of such *Earth Retaining Structures* is considered in Chapter 25. Shear Strength of soil is the property that is relevant in analyzing such problems and the analytical techniques that the Consulting Geotechnical Engineer uses are known as *Slope Stability Analysis* and *Earth Pressure Analysis*, which are discussed in Chapters 21 and 22.

## 3. Flow through Soil

We know that when it rains, the rain water either flows on the earth's surface and finds its way into drains, into rivers, into lakes, into oceans, etc.; or, it seeps into the ground and flowing through soil joins up with a reservoir of underground water. Some rain water, of course, also evaporates. Water impounded in ponds, in natural lakes or in man-made lakes created behind dams also evaporates and seeps through soils abutting the pond or lake. Some of the water flowing through unlined canals seeps out of the bottom and sides of the canal. When dams are constructed with soil, i.e. earth dams, water also seeps through the dam and emerges on the downstream end of the dam. In many such situations, Civil Engineers need to know how much water will seep through soil, what will be the velocity with which water will flow, will it carry soil particles with it and so on. Another problem related to flow of water is that of pollution of ground water from flow of water that has contaminants in it. The Consulting Geotechnical Engineer has to devise ways and means of controlling such pollution. The property of soil that controls the flow of water through it is called the *Permeability*; it is discussed in Chapters 5 and 6. Problems of flow are solved through an understanding of *Flow Analysis* which is discussed in Chapter 18. Solution to pollution-related problems are discussed in Chapters 35 to 38.

## 4. Soil as a Construction Material

Most of the time Civil Engineers view soil as a part of nature at the site where they have to construct structures. It is a given condition, a constraint that they have to reckon with. Soil plays a passive role. It is constructed upon. It has to be retained. It is through which water flows.

Soil takes on an active role only when the Civil Engineer has to use it as a construction material. In the construction of highways and railways, the ground along which the road has to be constructed or the track has to be laid is not always at the correct elevation. It then becomes necessary to *cut* soil at places and build up or *fill* other places with soil. The filling of soil, the Civil Engineer realized is not achieved by just dumping soil. The fill must be engineered so that it has properties that are suited to withstand the loads that will be imposed on it by the road or the railway track. These engineered fills are known as *earth embankments*. Soil is also used to construct earth dams – that is an engineered fill, which is designed to hold back water. Earth embankments and earth dams are exciting projects for the Consulting Geotechnical Engineer, because at each site he/she must construct them using the soils that exist at or very near the site – it is too costly to transport large quantities of soil from far away distances. Since soils that are available at or near any site are unique, the design of each earth structure is unique. The design of earth structures involves using *Flow Analysis, Settlement Analysis, Bearing Capacity Analysis, Slope Stability Analysis*; it, thus, offers great challenge to the Consulting Geotechnical Engineer. Creating the engineered fill also requires that soil be processed and compacted at the site. The *Engineering Properties of Man-made Deposits* are discussed in Chapter 15, the design of *Earth Structures* in Chapter 24 and how soil is excavated, moved, placed and compacted in Chapter 26 on *Earthwork*.

## B. Learning to be a Geotechnical Engineer

You now know the kinds of problems which you as a Consulting Geotechnical Engineer are expected to find solutions for. As you sit in your office, clients will come to you expecting you to design foundations for structures, retaining structures as well as earth structures, etc.

Let us say, an industrialist walks into your office to seek your advice in constructing the industrial complex he/she wishes to establish which includes factories, systems to dispose off industrial wastes, office and residential buildings, roads and so on. The industrialist might be coming to you when the site for establishing the complex has already been selected, or if he/she is really bright, might even be seeking your advice to select the right kind of site from alternative possibilities. You have to help. What do you need to know to be able to help? Let us draw up a list:

- (i) what are the various structures to be constructed?
- (ii) what are the soil/s at the site/s?
- (iii) what are the properties of these soils?
- (iv) what are alternative solutions?
- (v) what are the analytical tools you will need to analyze the viability of alternative solutions?
- (vi) what are the costs involved?
- (vii) what are the design procedures? and
- (viii) what are the means of construction?

Only with knowledge about all of the above would you be able to go through an engineering design process and come up with appropriate recommendations for your client. So, where and how are you going to acquire this knowledge? Let us consider each of the above listed eight items in turn:

(i) *Various structures* – The client will identify for you the requirements for the various structures. The client may not do this personally but through Systems Engineers, Architects, Structural Engineers, etc. They will provide you information about the layout, the dimensions, the loads, special functional requirements, etc. You must, of course, be able to understand the engineering implications of the

requirements and you will be able to do so because in the process of your study to become a Civil Engineer, you will be learning about various kinds of structures.

(ii) *Soils at the site* – Nature abounds in the types of soils that exist. You must know what are the different soils, be able to recognize them, be able to understand their genesis at the site where they exist, be able to classify them, be able to obtain samples of the different soils for testing to find their properties, etc. This you will learn from this Book in Chapters 1 and 17.

(iii) *Soil Properties* – It is useful to think of soil properties in two classes. The first class is that of physical properties which describe the physical state of soil: how wet is the soil, how dense is it, etc. The second class of properties is its engineering properties; these are indicative of how soil will behave from an engineering viewpoint. We have already seen that these are the *Permeability*, the *Compressibility* and the *Shear Strength*; there are some others as well. The physical properties are discussed in Chapter 2 on *The Three Phase System* and the engineering properties in Chapters 5, 6, 8, 10 through 16. Chapter 3 describes the *Effective Stress Principle* that has been discovered to be a unifying principle that enables us to get a good handle on understanding engineering properties. How we can determine this *Effective Stress* under various conditions is described in Chapters 4, 7 and 9.

(iv) *Alternative Solutions* – Engineering is not just a science but an art as well. The first engineer had no list of solutions to choose from. The first engineer innovated. Engineers continue to innovate. You too will innovate. You of course also have the advantage of history. There are many solutions that have already worked and you can take advantage of the experience of past engineers. Their experience is documented and some of this experience has been described in various chapters of this Book, especially in Chapters 23, 24, 25, 27, 28, 30 to 33 and 36 to 38.

(v) *Analytical Techniques* – Physical problems are really much too complicated. Engineers have learnt to idealize reality so that it lends itself to mathematical analysis. The techniques are described in Chapters 18 through 22.

(vi) *Costs* – An inherent characteristic of a good engineering solution is that it must perform the task in an economical fashion. Costs do not remain constant. They vary both with time and at any given time vary from place to place. The Consulting Geotechnical Engineer invariably has to keep abreast of market conditions. You will get information about costs from local dealers and contractors.

(vii) *Design Procedure* – The process of design has definite components and a particular sequence that needs to be followed. The philosophy of design and the relevant procedures are described in Chapters 23 to 25, 31, 32, and 36 to 38. Each nation codifies design procedures to assist the design engineer. The Consulting Geotechnical Engineer must be familiar with codes and use them to the extent they are applicable.

(viii) *Construction Methods* – Technology keeps on evolving. In days gone by excavated soil was moved by donkeys, today it is moved by huge motorized vehicles. Construction techniques impact design and increase options. You will need to keep abreast of technology and techniques. Some current practices are summarized in Chapters 26 to 31 and 39.

## C. This Book

This Book is designed for you.

It assumes that you are shortly going to set up your office as a Consulting Geotechnical Engineer. It hopes that it can help you get started and be your constant referral document. It attempts to anticipate

the questions that will arise as you learn and practice Geotechnical Engineering and it is there to help you to either find the answers or guide you to suitable sources where you will find the answers.

The Book is in eight parts.

The first is on **Soil: Material Characterization**. It emphasizes the diversity in soils. Properties of a particular grade of steel are constant regardless of where the steel has been manufactured. The properties can be and are listed in a manual. Similarly, the properties of a particular grade of concrete are constant and are tabulated. Soil is a material found in nature. It varies from place to place and at a particular place it varies with depth below the ground surface. Every soil has a unique set of properties that are different from every other soil. We, therefore, cannot begin to function as Consulting Geotechnical Engineers until we first understand and determine the properties of the soil that we are to deal with.

**Site: Location Characterization** constitutes the second part. Each site is different. We need to determine the *soil profile*. Get soil samples for laboratory testing or test soils in the field. A great deal of technology is involved that we must familiarize ourselves with.

The third part on **Analytical Techniques** describes the mathematical tools we possess to assess the viability of proposed solutions by enabling us to estimate the magnitudes of parameters that indicate performance and safety. Over the years, an abundance of techniques have been developed that attempt to increase the degree of sophistication of the analysis. An impetus to this development was the advent of the computer that allows us to use methods that involve making thousands of calculations because we no longer have to make them ourselves. Many techniques are now packaged in black boxes that we need not look into. We just provide the stipulated input data and the black box cranks out the answer. Those that use these packages must do so carefully remembering the famous adage of the computer world that if we put ‘garbage in’ we only get ‘garbage out’. The Book does not focus on these boxes but on methods that will give you a ‘feel’ for solving problems. Once you have the feel, you can always take advantage of the boxes.

The fourth part focuses on **Engineering Design**, i.e. the development of the final output that is expected out of the office of the Consulting Geotechnical Engineer. It highlights that designing is an iterative process and that engineering judgement continues to play a very significant role in designing.

The fifth part is on **Geotechnical Construction**. In the profession, engineers have to play many roles, for example, design, construct, maintain, etc. Depending on the role played, we designate them as Design Engineers, Construction Engineers, Maintenance Engineers, etc. Civil Engineering has many specializations and depending on the expertise, we also designate them as Structural Engineers, Water Resources Engineers, Geotechnical Engineers. We can combine these and come up with, say, Structural Design Engineer, Water Resources Construction Engineer and so on. This Book is for you, a potential Consulting Geotechnical Engineer. Clearly, the Consulting Geotechnical Engineer is a specialist in Geotechnical Engineering and understands soils. He/she must be able to advise on any aspect related to soils be it delineating soil profiles, determining soil properties, analyzing, designing, constructing, etc. There are aspects of construction which are unique to soils. How to drive or install piles in soil, how to excavate and compact soil, how to drill tunnels through soil, etc. You as the Consulting Geotechnical Engineer will have to make the choices and shoulder ultimate responsibility and so you need to be aware and knowledgeable.

No longer do we have to accept every site as we find it. Often, we can do something about changing the properties of soil and the sixth part of the Book on **Ground Engineering** is devoted to describing how.

With urbanization, industrialization and the development of our modern life style we have created an enormous problem of generation of large quantities of waste as highlighted in Chapter 34. Some are inert, some biodegradable and some are toxic and hazardous. The need for sensible disposal of the waste has created new demands on the Consulting Geotechnical Engineer and the seventh part of the Book on ***Geoenvironmental Engineering*** caters to this new field.

The entire Book deals with soil behaviour and engineering when soil is subjected to static loads. Soil is, however, subjected to dynamic loads also both by nature and man. The last, the eighth part of the Book on ***Soil Dynamics*** is a mere introduction to this subject and is included to sensitize you to the factors that assume importance when soil has to withstand dynamic loads arising from just two important sources: machines and earthquakes.

This Book is for you, so do get started.