JEAN-LOUIS BRIAUD

GEOTECHNICAL ENGINEERING

UNSATURATED AND SATURATED SOILS

SECOND EDITION

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Geotechnical Engineering: Unsaturated and Saturated Soils

Geotechnical Engineering: Unsaturated and Saturated Soils

Second Edition

Jean-Louis Briaud

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SECOND EDITION

The new chapter on case histories required many figures to be redrawn. Anna Timchenko stands out as the one who single-handedly, patiently, and very reliably prepared dozens of figures for that chapter. Others making significant contributions to the illustrations in the second edition include Jerome Sfeir, Erick Cruz, Tehseena Ali, Anna Shidlovskaya, and Blake Thurman.

Anna TIMCHENKO

Jerome SFEIR

Erick CRUZ

Tehseena ALI

Anna SHIDLOVSKAYA

Blake THURMAN

CHAPTER 1

Introduction

1.1 WHY THIS BOOK?

> "Things should be made as simple as possible but not a bit simpler than that."
> *Albert Einstein* (*Safir and Safire, 1982*)

Finding the Einstein threshold of optimum simplicity was a constant goal for the author when writing this book (Figure 1.1). The first driving force for writing it was the coming of age of unsaturated soil mechanics: There was a need to introduce geotechnical engineering as dealing with true three-phase soils while treating saturated soil as a special case, rather than the other way around. The second driving force was to cover as many geotechnical engineering topics as reasonably possible in an introductory book, to show the vast domain covered by geotechnical engineering and its important contributions to society. Dams, bridges, buildings, pavements, landfills, tunnels, and many other infrastructure elements involve geotechnical engineering. The driving force for the second edition was the desire to include case histories to further demonstrate the considerable role played by geotechnical engineers in society and also to update the first edition. The intended audience is anyone who is starting in the field of geotechnical engineering, including university students.

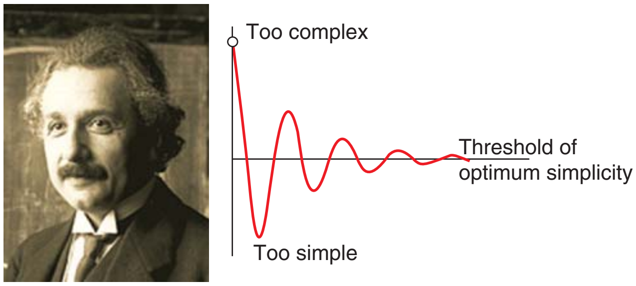

Figure 1.1 Einstein threshold of optimum simplicity. (Source: Photo by Ferdinand Schmutzer.)

1.2 GEOTECHNICAL ENGINEERING

Geotechnical engineering is a young (~100 years) professional field dealing with soils within a few hundred meters of a planet's surface for the purpose of civil engineering structures. For geotechnical engineers, soils can be defined as loosely bound to unbound, naturally occurring materials that cover the top few hundred meters of a planet. In contrast, rock is a strongly bound, naturally occurring material found within similar depths or deeper. At the boundary between soils and rocks are intermediate geo-materials. The classification tests and the range of properties described in this book help to distinguish between these three types of naturally occurring materials. Geotechnical engineers must make decisions in the best interest of the public with respect to safety and economy. Their decisions are related to topics such as:

- Foundations
- Slopes
- Retaining walls
- Dams
- Landfills
- Tunnels

These geotechnical structures or projects are subjected to loads, which include:

- Loads from a structure
- Weight of a slope
- Push on a retaining wall
- Environmental loads, such as waves, wind, rivers, earthquakes, floods, droughts, and chemical changes, among others

Note that current practice is based on testing an extremely small portion of the soil or rock present in the project area. A typical soil investigation might involve testing 0.0001% of the soil that will provide the foundation support for the structure. Yet, on the basis of this extremely limited data, the

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Geotechnical Engineering: Unsaturated and Saturated Soils, Second Edition. Jean-Louis Briaud.
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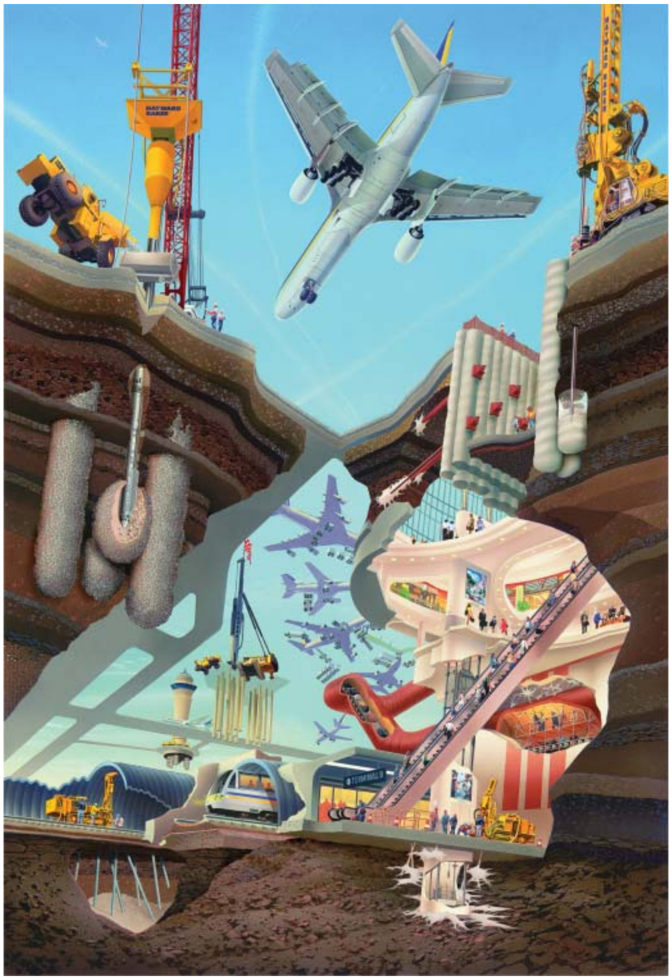

Figure 1.2 A rendition of the geotechnical engineering world. (Source: Courtesy of Hayward Baker Inc., Geotechnical Contractor.)

geotechnical engineer must predict the behavior of the entire heterogeneous mass of soil. This is why geotechnical engineering is a very difficult discipline. Yet, as Terzaghi is said to have noted, there is no glory in foundations. Indeed, most of our work is buried (Figure 1.2). For example, everyone knows the Eiffel Tower in Paris, but very few know about its foundation.

1.3 THE PAST AND THE FUTURE

While it is commonly agreed that geotechnical engineering started with the work of Karl Terzaghi at the beginning of the 20th century, history is rich in instances where soils and soils-related engineering played an important role in the evolution of humankind (Kerisel, 1985; Peck, 1985; Skempton, 1985). In prehistoric times (before 3000 BC), soil was used as a building material. In ancient times (3000–300 BC), roads, canals, and bridges were very important to warriors. In Roman times (300 BC–300 AD), structures started to become larger and foundations could no longer be ignored. The Middle Ages (AD 300–1400) were mainly a period of war, in which structures became even heavier, including castles and cathedrals with very thick walls. Severe settlements and instabilities were experienced. The Renaissance (AD 1400–1650) was a period of enormous development in the arts, and several great artists proved to be great engineers as well. This was the case of Leonardo da Vinci and more particularly Michelangelo. Modern times (AD 1650–1900) saw significant engineering development, with a shift from military engineering to civil engineering. In 1776, Charles Coulomb developed his earth pressure theory, followed in 1855 by Henry Darcy and his seepage law. In 1857, William Rankine proposed his own earth pressure theory, closely followed by Carl Culman and his graphical earth pressure solution. In 1882, Otto Mohr presented his stress theory and the famous Mohr circle, and in 1885 Joseph Boussinesq provided the solution to an important elasticity problem for soils.

From 1900 to 2000 was the true period of development of modern geotechnical engineering, with the publication of Karl Terzaghi's book *Erdbaumechanik* (in 1925), which was soon translated into English; new editions were co-authored with Ralph Peck, beginning in 1948. The progress over the past 50 years has been stunning, with advances in the understanding of fundamental soil behavior and associated soil models (e.g., unsaturated soils), numerical simulations made possible by the computer revolution, the development of large machines (e.g., drill rigs for bored piles), and a number of ingenious ideas (e.g., reinforced earth walls, pile driving analyzer, geosynthetics).

Geotechnical engineering has transcended the ages because all structures built on or in a planet have to rest on a soil or rock surface; as a result, the geotechnical engineer is here to stay and will continue to be a very important part of humanity's evolution. The Tower of Pisa is one of the most famous examples of a project that did not go as planned, mostly because of the limited knowledge extant some 900 years ago. Today designing a proper foundation for the Tower of Pisa is a very simple exercise, because of our progress. One cannot help but project another 900 years ahead and wonder what progress will have been made. Will we have:

- complete nonintrusive site investigation of the entire soil volume?
- automated four-dimensional (4D) computer-generated design by voice recognition and based on a target risk?
- tiny and easily installed instruments to monitor geotechnical structures?
- unmanned robotic machines working at great depth?
- significant development of the underground?
- extension of projects into the sea?
- soil structure interaction extended to thermal and magnetic engineering?
- failures down to a minimum?
- expert systems to optimize repair of defective geotechnical engineering projects?
- geospace engineering of other planets?
- geotechnical engineers with advanced engineering judgment taught in universities?
- no more lawyers, because of the drastic increase in project reliability?

1.4 GEOTECHNICAL ENGINEERING CAN BE FUN

Geotechnical engineering can be fun and entertaining, as the book by Elton (1999) on geo-magic demonstrates. Such phenomena as the magic sand (watch this video: https://www.stevespanglerscience.com/lab/experiments/magic-hydrophobic-sand/), water going uphill, the surprisingly strong sand pile (Figure 1.3e), the swelling clay pie (Figure 1.3d), and the suddenly very stiff glove full of sand will puzzle the uninitiated. Geotechnical engineering is seldom boring; indeed: the complexity of soil deposits and soil behavior can always surprise us with unanticipated results. The best geotechnical engineering work will always include considerations regarding geology, proper site characterization, sound fundamental soil mechanics principles, advanced knowledge of all the tools available, keen observation, and engineering

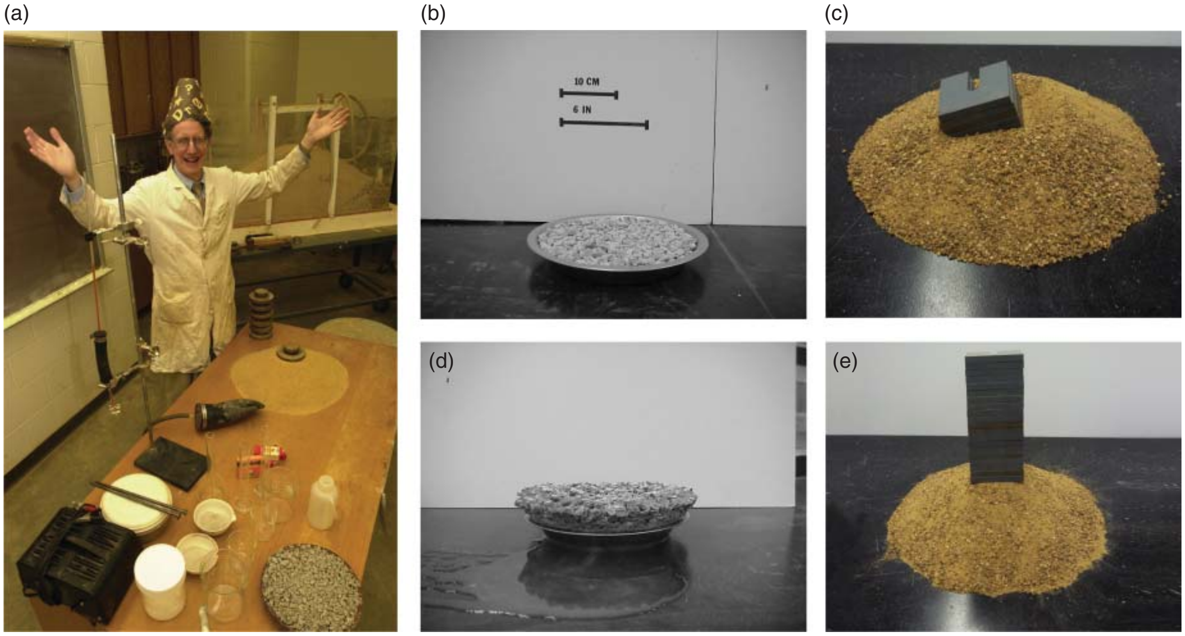

Figure 1.3 Soil magic. (Source: Courtesy of David J. Elton.)

judgment. The fact that geotechnical engineering is so complex makes this field an unending discovery process, which keeps the interest of its adepts over their lifetimes.

1.5 UNITS

In engineering, a number without units is usually worthless and often dangerous. On this planet, the unit system most commonly used in geotechnical engineering is the System International or SI system. In the SI system, the unit of mass is the *kilogram* (kg), which is defined as the mass of a platinum-iridium international prototype kept at the International Bureau of Weights and Measures in Paris, France. On Earth, the kilogram-mass weighs about the same as 10 small apples. The unit of length is the *meter*, defined as the length of the path traveled by light in a vacuum during a time interval of 1/299,792,458 of a second. A meter is about the length of a big step for an average human. The *second* is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom. Watches and clocks often have a hand ticking off the seconds. The unit of temperature is the Kelvin, defined as 1/273.16 of the difference in temperature between the absolute zero and the triple point of water. The *degree Celsius* (C) is also commonly used; it has the same magnitude as the degree Kelvin but starts at ~0°C (~273 K) for the freezing point of water and uses ~100°C (~373 K) for the boiling point of water. There are seven fundamental units in a unit system, but these four (kg, m, s, K) are the most commonly used in geotechnical engineering. The other fundamental units in the SI system are the mole (substance), the candela (light), and the ampere (electricity).

Other geotechnical engineering units are derived from these fundamental units. The unit of force is the *Newton*, which is the force required to accelerate a mass of 1 kg to 1 m/s^2.

$$1 \text{ N} = 1 \text{ kg} \times 1 \text{ m/s}^2 \tag{1.1}$$

This force is about the weight of a small apple. Humans typically weigh between 600 and 1000 N. Most often the kilo-Newton (kN) is used rather than the Newton. The kilogram force is the weight of one kilogram mass. On Earth, the equation is:

$$1 \text{ kgf} = 1 \text{ kg} \times 9.81 \text{ m/s}^2 \tag{1.2}$$

The unit of stress is the kN/m^2, also called the kilo-Pascal (kPa); there is about 20 kPa under your feet when you stand on both feet. Note that a kilogram force is the weight of a kilogram mass and depends on what planet you are on and even where you are on Earth.

Accepted multiples of units, also called SI prefixes, are:

terra	10^{12}
giga	10^{9}
mega	10^{6}
kilo	10^{3}
milli	10^{-3}
micro	10^{-6}
nano	10^{-9}
pico	10^{-12}

(An angstrom is 10^{-10} meter.)

Problems and Solutions

Problem 1.1

How would you decide if you have reached the threshold of optimum simplicity?

Solution 1.1

The threshold is not reached if:

- The solution seems too simple or too complicated.
- The solution is not used in practice.
- It costs too much time and money to obtain the solution.
- The solution leads to erroneous answers.
- The solution does not contain or address the essential elements of the problem.

The threshold is likely reached if:

- The solution seems reasonably simple and cannot be simplified further.
- The solution is used in practice.
- The cost of obtaining and implementing the solution is consistent with the budget of a large number of projects.
- The solution leads to reasonable answers.
- The solution is based on fundamental elements of the problem.