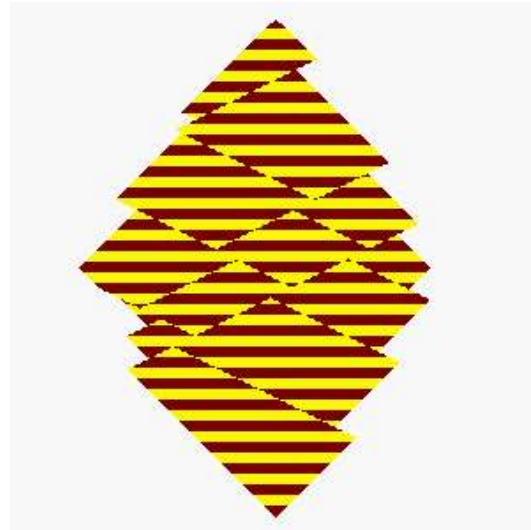


SOIL MECHANICS

Arnold Verruijt

Delft University of Technology, 2001, 2006



This is the screen version of the book SOIL MECHANICS, used at the Delft University of Technology.

It can be read using the Adobe Acrobat Reader. Bookmarks are included to search for a chapter.

The book is also available in Dutch, in the file GrondMechBoek.pdf.

Exercises and a summary of the material, including graphical illustrations, are contained in the file SOLMEX.ZIP.

All software can be downloaded from the website <http://geo.verruijt.net/>.

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PREFACE

This book is the text for the introductory course of Soil Mechanics in the Department of Civil Engineering of the Delft University of Technology, as I have given from 1980 until my retirement in 2002. It contains an introduction into the major principles and methods of soil mechanics, such as the analysis of stresses, deformations, and stability. The most important methods of determining soil parameters, in the laboratory and in situ, are also described. Some basic principles of applied mechanics that are frequently used are presented in Appendices. The subdivision into chapters is such that one chapter can be treated in a single lecture, approximately.

Comments of students and other users on the material in earlier versions of this book have been implemented in the present version, and errors have been corrected. Remaining errors are the author's responsibility, of course, and all comments will be appreciated.

An important contribution to the production of the printed edition, and to this screen edition, has been the typesetting program \TeX , by Donald Knuth, in the \LaTeX implementation by Leslie Lamport. Most of the figures have been constructed in \LaTeX , using the \PCTeX macros.

The logo was produced by Professor G. de Josselin de Jong, who played an important role in developing soil mechanics as a branch of science, and who taught me soil mechanics.

Since 2001 the English version of this book has been made available on the internet, on the website \langle <http://geo.verruijt.net> \rangle . Several users, from all over the world, have been kind enough to send me their comments or their suggestions for corrections or improvements. In recent versions of the screenbook it has also been attempted to incorporate the figures better into the text, using the macro `wrapfigure`, and colors. In this way the appearance of many pages seems to have been improved.

Papendrecht, March 2006

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Chapter 1

INTRODUCTION

1.1 The discipline

Soil mechanics is the science of equilibrium and motion of soil bodies. Here soil is understood to be the weathered material in the upper layers of the earth's crust. The non-weathered material in this crust is denoted as *rock*, and its mechanics is the discipline of *rock mechanics*. In general the difference between soil and rock is roughly that in soils it is possible to dig a trench with simple tools such as a spade or even by hand. In rock this is impossible, it must first be splintered with heavy equipment such as a chisel, a hammer or a mechanical drilling device. The natural weathering process of rock is that under the long-term influence of sun, rain and wind, it degenerates into stones. This process is stimulated by fracturing of rock bodies by freezing and thawing of the water in small crevices in the rock. The coarse stones that are created in mountainous areas are transported downstream by gravity, often together with water in rivers. By internal friction the stones are gradually reduced in size, so that the material becomes gradually finer: gravel, sand and eventually silt. In flowing rivers the material may be deposited, the coarsest material at high velocities, but the finer material only at very small velocities. This means that gravel will be found in the upper reaches of a river bed, and finer material such as sand and silt in the lower reaches.

The Netherlands is located in the lower reaches of the rivers Rhine and Meuse. In general the soil consists of weathered material, mainly sand and clay. This material has been deposited in earlier times in the delta formed by the rivers. Much fine material has also been deposited by flooding of the land by the sea and the rivers. This process of sedimentation occurs in many areas in the world, such as the deltas of the Nile and the rivers in India and China. In the Netherlands it has come to an end by preventing the rivers and the sea from flooding by building dikes. The process of land forming has thus been stopped, but subsidence continues, by slow tectonic movements. In order to compensate for the subsidence of the land, and sea water level rise, the dikes must gradually be raised, so that they become heavier and cause more subsidence. This process must continue forever if the country is to be maintained.

People use the land to live on, and build all sort of structures: houses, roads, bridges, etcetera. It is the task of the geotechnical engineer to predict the behavior of the soil as a result of these human activities. The problems that arise are, for instance, the settlement of a road or a railway under the influence of its own weight and the traffic load, the margin of safety of an earth retaining structure (a dike, a quay wall or a sheet pile wall), the earth pressure acting upon a tunnel or a sluice, or the allowable loads and the settlements of the foundation of a building. For all these problems soil mechanics should provide the basic knowledge.

1.2 History

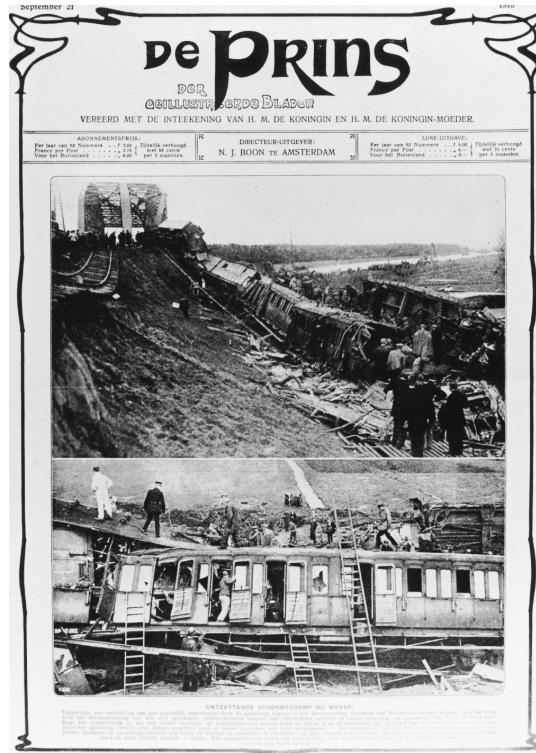


Figure 1.1: Landslide near Weesp, 1918.

Soil mechanics has been developed in the beginning of the 20th century. The need for the analysis of the behavior of soils arose in many countries, often as a result of spectacular accidents, such as landslides and failures of foundations. In the Netherlands the slide of a railway embankment near Weesp, in 1918 (see Figure 1.1) gave rise to the first systematic investigation in the field of soil mechanics, by a special commission set up by the government. Many of the basic principles of soil mechanics were well known at that time, but their combination to an engineering discipline had not yet been completed. The first important contributions to soil mechanics are due to Coulomb, who published an important treatise on the failure of soils in 1776, and to Rankine, who published an article on the possible states of stress in soils in 1857. In 1856 Darcy published his famous work on the permeability of soils, for the water supply of the city of Dijon. The principles of the mechanics of continua, including statics and strength of materials, were also well known in the 19th century, due to the work of Newton, Cauchy, Navier and Boussinesq. The union of all these fundamentals to a coherent discipline had to wait until the 20th century. It may be mentioned that the committee to investigate the disaster near Weesp came to the conclusion that the water levels in the railway embankment had risen by sustained rainfall, and that the embankment's strength was insufficient to withstand these high water pressures.

Important pioneering contributions to the development of soil mechanics were made by Karl Terzaghi, who, among many other things, has described how to deal with the influence of the pressures of the pore water on the behavior of soils. This is an essential element of soil mechanics theory. Mistakes on this aspect often lead to large disasters, such as the slides near Weesp, Aberfan (Wales) and the Teton Valley Dam disaster. In the Netherlands much pioneering work was done by Keverling Buisman, especially on the

deformation rates of clay. A stimulating factor has been the establishment of the Delft Soil Mechanics Laboratory in 1934, now known as GeoDelft. In many countries of the world there are similar institutes and consulting companies that specialize on soil mechanics. Usually they also deal with *Foundation engineering*, which is concerned with the application of soil mechanics principle to the design and the construction of foundations in engineering practice. Soil mechanics and Foundation engineering together are often denoted as *Geotechnics*. A well known

consulting company in this field is Fugro, with its head office in Leidschendam, and branch offices all over the world.

The international organization in the field of geotechnics is the *International Society for Soil Mechanics and Geotechnical Engineering*, the ISSMGE, which organizes conferences and stimulates the further development of geotechnics by setting up international study groups and by standardization. In most countries the International Society has a national society. In the Netherlands this is the Department of Geotechnics of the Royal Netherlands Institution of Engineers (KIVI), with about 1000 members.

1.3 Why Soil Mechanics ?

Soil mechanics has become a distinct and separate branch of engineering mechanics because soils have a number of special properties, which distinguish the material from other materials. Its development has also been stimulated, of course, by the wide range of applications of soil engineering in civil engineering, as all structures require a sound foundation and should transfer its loads to the soil. The most important special properties of soils will be described briefly in this chapter. In further chapters they will be treated in greater detail, concentrating on quantitative methods of analysis.

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1.3.1 Stiffness dependent upon stress level

Many engineering materials, such as metals, but also concrete and wood, exhibit linear stress-strain-behavior, at least up to a certain stress level. This means that the deformations will be twice as large if the stresses are twice as large. This property is described by Hooke's law, and the materials are called *linear elastic*. Soils do not satisfy this law. For instance, in compression soil becomes gradually stiffer. At the surface sand will slip easily through the fingers, but under a certain compressive stress it gains an ever increasing stiffness and strength. This is mainly caused by the increase of the forces between the individual particles, which gives the structure of particles an increasing strength. This property is used in daily life by the packaging of coffee and other granular materials by a plastic envelope, and the application of vacuum inside the package. The package becomes very hard when the air is evacuated from it. In civil engineering the non-linear property is used to great advantage in the pile foundation for a building on very soft soil, underlain by a layer of sand. In the sand below a thick deposit of soft clay the stress level is high, due to the weight of the clay. This makes the sand very hard and strong, and it is possible to apply large compressive forces to the piles, provided that they are long enough to reach well into the sand.

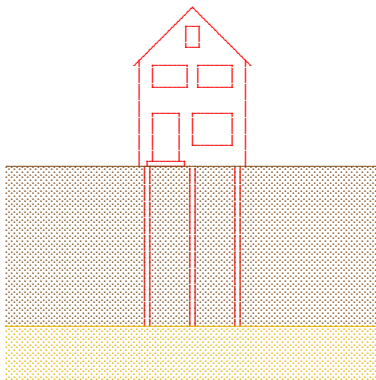


Figure 1.2: Pile foundation.