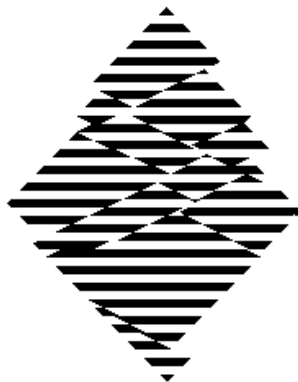


# **Soil Mechanics**

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**A. Verruijt**

**Revised by S. van Baars**



VSSD

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# Preface

This book is part of the introductory course of Soil Mechanics in the Department of Civil Engineering of the Delft University of Technology. 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 of 45 minutes, 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.

Several users, from all over the world, have been kind enough to send me their comments or their suggestions for corrections or improvements.

The "double sliding" 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.

Zoetermeer, November 2002

Arnold Verruijt

In this new edition several small, but also some major adjustments have been carried through. Not only pressure, instead of tension, but also settlement and volume decrease are defined positive. Besides this, more attention is given to the difference between the failure criterion of Coulomb (based on one normal stress) and the failure criterion of Mohr-Coulomb (based on two principal stresses). Especially the shear tests reflect this difference. My special thanks goes out to Prof.dr.ir. A. Verruijt, who taught me the fundamentals of Soil Mechanics and gave me the opportunity to revise this book to the developments the Geotechnical Engineering is undergoing.

Delft, May 2007

Stefan Van Baars

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# **Part I**

## **Introduction**

# 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 in the long run the 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 will probably 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 behaviour 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

Soil mechanics has been developed in the beginning of the 20th century. The need for the analysis of the behaviour 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 behaviour 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 and soon as Deltaris. 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* or *Geo-Engineering*.

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 a pile foundation for buildings 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 reach into the sand.

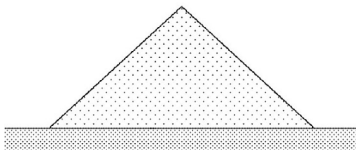


Figure 1-2. A heap of sand.

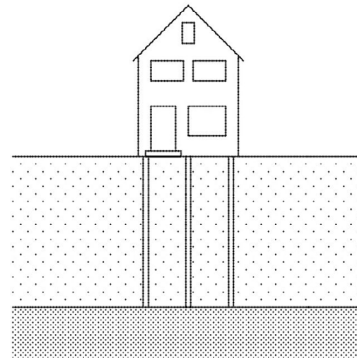


Figure 1-3. Pile foundation.

### 1.3.2 Shear

In compression soils become gradually stiffer. In shear, however, soils become gradually softer, and if the shear stresses reach a certain level, with respect to the normal stresses, it is even possible that failure of the soil mass occurs. This means that the slope of a sand heap, for instance in a depot or in a dam, can not be larger than about 30 or 40 degrees. The reason for this is that particles would slide over each other at greater slopes. As a consequence of this phenomenon many countries in deltas of large rivers are very flat. It has also caused the failure of dams and embankments all over the world, sometimes with very serious consequences for the local population. Especially dangerous is that in very fine materials, such as clay, a steep slope is often possible for some time, due to capillary pressures in the water, but after some time these capillary pressures may vanish (perhaps because of rain), and the slope will fail.

A positive application of the failure of soils in shear is the construction of guard rails along highways. After a collision by a vehicle the foundation of the guard rail will rotate in the soil due to the large shear stresses between this foundation and the soil body around it. This will dissipate large amounts of energy (into heat), creating a

years. This results in increasing stresses in the subsoil, and therefore causes additional settlements. This process will continue forever. Before the construction of the dikes the land was flooded now and then, with sediment being deposited on the land. This process has been stopped by man building dikes. Safety has an ever increasing price.

Sand and rock show practically no creep, except at very high stress levels. This may be relevant when predicting the deformation of porous layers from which gas or oil are extracted.

### 1.3.5 Groundwater

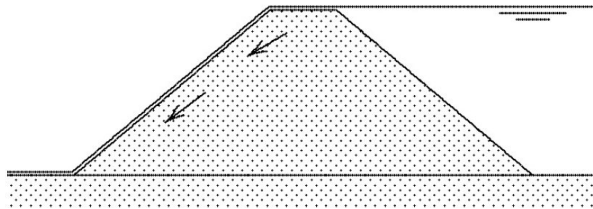


Figure 1-5. Overflowing dike.

A special characteristic of soil is that water may be present in the pores of the soil. This water contributes to the stress transfer in the soil. It may also be flowing with respect to the granular particles, which creates friction stresses between the fluid and the solid material. In many cases soil must be considered as a two phase material. As it takes some time before water can be expelled from a soil mass, the presence of water usually prevents rapid volume changes.

In many cases the influence of the groundwater has been very large. In 1953 in the Netherlands many dikes in the south-west of the country failed because water flowed over them, penetrated the soil, and then flowed through the dike, with a friction force acting upon the dike material. see Figure 1-5. The force of the water on and inside the dike made the slope slide down, so that the dike lost its water retaining capacity, and the low lying land was flooded in a short time.

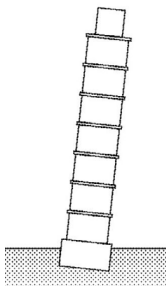


Figure 1-6. Pisa.

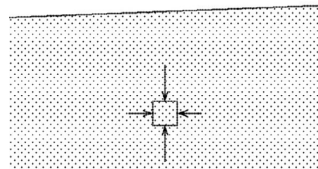


Figure 1-7. Stresses.