Chapter 1
Introduction

In this introductory chapter some of the characteristic properties of soils are described, and the reasons for soil mechanics as a separate subject of engineering are given.

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.

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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

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 Fig. 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 Terzaghi (1925), 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 Idaho, USA. In the Netherlands much pioneering work was done by Keverling Buisman, especially on the deformation rates of clay. A stimulating factor

Fig. 1.1 Landslide near Weesp, 1918

has been the establishment of the Delft Soil Mechanics Laboratory in 1934, now known as Deltares. 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 800 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.

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 (Fig. 1.2).

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°. The reason for this is that particles would slide over each other at greater slopes. As a consequence of this phenomenon many areas 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 dan-

Fig. 1.2 Pile foundation

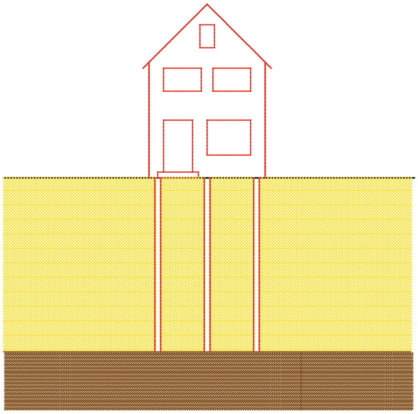
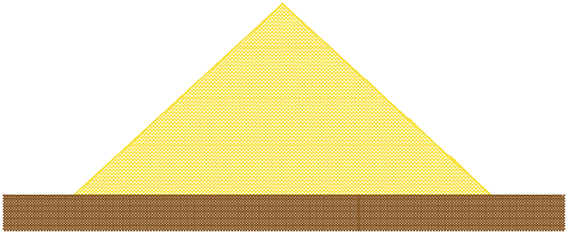


Fig. 1.3 A heap of sand



gerous 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 (Fig. 1.3).

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 permanent deformation of the foundation of the rail, but the passengers, and the car, may be unharmed. Of course, the guard rail must be repaired after the collision, which can relatively easily be done with the aid of a heavy vehicle.

1.3.3 Dilatancy

Shear deformations of soils often are accompanied by volume changes. Loose sand has a tendency to contract to a smaller volume, and densely packed sand can practically deform only when the volume expands somewhat, making the sand looser. This is called *dilatancy*, a phenomenon discovered by Reynolds, in 1885. This property causes the soil around a human foot on the beach near the water line to be drawn dry during walking. The densely packed sand is loaded by the weight of the foot, which causes a shear deformation, which in turn causes a volume expansion, which sucks in some water from the surrounding soil. The expansion of a dense soil during shear is shown in Fig. 1.4. The space between the particles increases when they shear over each other.

On the other hand a very loose assembly of sand particles will have a tendency to collapse when it is sheared, with a decrease of the volume. Such volume deformations may be especially dangerous when the soil is saturated with water. The tendency for volume decrease then may lead to a large increase in the pore water pressures. Many geotechnical accidents have been caused by increasing pore water pressures. During earth quakes in Japan, for instance, saturated sand is sometimes densified in a short time, which causes large pore pressures to develop, so that the sand particles may start to float in the water. This phenomenon is called *liquefaction*. In the Netherlands the original sand in the channels in the Eastern Scheldt estuary was very loose, which required large densification works before the construction of the storm surge barrier. Also, the sand used to create the airport Tjek Lap Kok in Hongkong was densified before the construction of the runways and the facilities of the airport.

1.3.4 Creep

The deformations of a soil often depend upon time, even under a constant load. This is called *creep*. Clay and peat exhibit this phenomenon. It causes structures founded on soft soils to show ever increasing settlements. A new road, built on a soft soil, will continue to settle for many years, and it must be repaired from time to time. For buildings such settlements are particular damaging when they are not uniform, as this may lead to cracks in the building.

The building of dikes in the Netherlands, on compressible layers of clay and peat, results in settlements of these layers that continue for many decades. In order to maintain the level of the crest of the dikes, they must be raised after a number of 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.

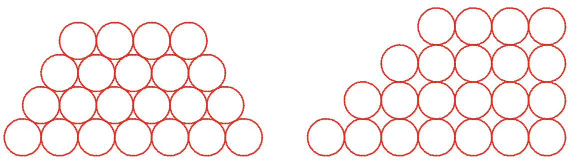


Fig. 1.4 Dilatancy

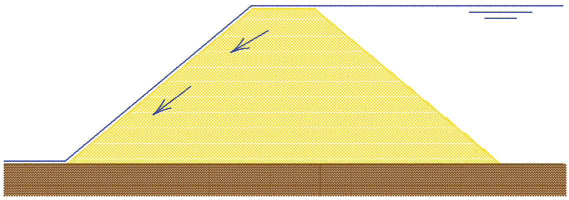


Fig. 1.5 Overflowing dike

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

1.3.5 Groundwater

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 Fig. 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. This has lead to a program (the Delta works) for increasing the level of the dikes and closing several river channels.

In other countries of the world large dams have sometimes failed also because of rising water tables in the interior of the dam (for example, the Teton Valley Dam in the USA, in which water could enter the coarse dam material because of a leaky clay core). Even excessive rainfall may fill up a dam, as happened near Aberfan in Wales in 1966, when a dam of mine tailings collapsed onto the village.

It is also very important that lowering the water pressures in a soil, for instance by the production of groundwater for drinking purposes, leads to an increase of the stresses between the particles, which results in settlements of the soil. This happens in many big cities, such as Venice and Bangkok, that may be threatened to be swallowed by the sea. It also occurs when a groundwater table is temporarily lowered for the construction of a dry excavation. Buildings in the vicinity of the excavation may be damaged by lowering the groundwater table. On a different scale the same phenomenon occurs in gas or oil fields, where the production of gas or oil leads to a volume decrease of the reservoir, and thus to subsidence of the soil. The production of natural gas from the large reservoir in Groningen is estimated to result in a subsidence of about 50 cm in the production time of the reservoir.

1.3.6 Unknown Initial Stresses

Soil is a natural material, created in historical times by various geological processes. Therefore the initial state of stress is often not uniform, and often even partly unknown. Because of the non-linear behavior of the material, mentioned above, the initial stresses in the soil are of great importance for the determination of soil behavior under additional loads. These initial stresses depend upon geological history, which is never exactly known, and this causes considerable uncertainty. In particular, the initial horizontal stresses in a soil mass are usually unknown. The initial vertical stresses may be determined by the weight of the overlying layers. This means that the stresses increase with depth, and therefore stiffness and strength also increase with depth. The horizontal stresses, however, usually remain largely unknown. When the soil has been compressed horizontally in earlier times, it can be expected that the horizontal stress is high, but when the soil is known to have spread out, the horizontal stresses may be very low. Together with the stress dependency of the soil behavior

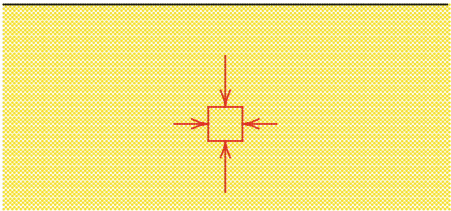


Fig. 1.6 Stresses

Fig. 1.7 Pisa

all this means that there may be considerable uncertainty about the initial behavior of a soil mass. It may also be noted that further theoretical study can not provide much help in this matter. Studying field history, or visiting the site, and talking to local people, may be more helpful (Fig. 1.6).

1.3.7 Variability

The creation of soil by ancient geological processes also means that soil properties may be rather different on different locations. Even in two very close locations the soil properties may be completely different, for instance when an ancient river channel has been filled with sand deposits. Sometimes the course of an ancient river can be traced on the surface of a soil, but often it can not be seen at the surface. When an embankment is built on such a soil, it can be expected that the settlements will vary, depending upon the local material in the subsoil. The variability of soil properties may also be the result of a heavy local load in the past (Fig. 1.7).

A global impression of the soil composition can be obtained from geological maps. These indicate the geological history and character of the soils. Together with geological knowledge and experience this may give a first indication of the soil properties. Other geological information may also be helpful. Large areas of Western Europe have, for instance, been covered by thick layers of ice in earlier ice ages, and this means that the soils in these areas have been subject to a preload of considerable magnitude, and therefore may be rather dense. An accurate determination of soil properties can not be made from desk studies. It requires testing of the actual soils in the laboratory, using samples taken from the field, or testing of the soil in the field (in situ). This will be elaborated in later chapters.

Problem 1.1 In times of high water in the rivers in The Netherlands, when the water table rises practically to the crest of the dikes, local authorities sometimes put sand bags on top of the dike. Is that useful?

Problem 1.2 Another measure to prevent failure of a dike during high floods, is to place large sheets of plastic on the slope of the dike. On which side?

Fig. 1.8 Delft

Problem 1.3 Will the horizontal stress in the soil mass near a deep river be relatively large or small?

Problem 1.4 The soil at the bottom of the North Sea is often much stiffer in the Northern parts (near Norway) than it is in the Southern parts (near London). What can be the cause?

Problem 1.5 A possible explanation for the leaning of the Pisa tower is that the subsoil contains a compressible clay layer of variable thickness. On what side of the tower would that clay layer be thickest?

Problem 1.6 Another explanation for the leaning of the Pisa tower is that in earlier ages (before the start of the building of the tower, in 1400) a heavy structure stood near that location. On which side of the tower would that building have been?

Problem 1.7 In many cities of the world leaning towers may be found, though nowhere so spectacular as in Pisa. An example is shown in Fig. 1.8 of the tower of the Old Church of Delft, along the canal Oude Delft. Can you imagine what is the probable cause in this case, and can you suggest a technical solution to prevent further leaning?

Reference

K. Terzaghi, *Erdbaumechanik auf bodenphysikalischer Grundlage* (Deuticke, Wien, 1925)