1 Granular Materials as Soft Solids

1.1 Soil and Geotechnical Engineering

Our solid underground consists of soil and rock; soil being the more important, as our cities are mainly built on it. One usually considers the underground as fixed, and thus, confidently introduces the load of buildings into the soil. However, engineers gradually realised that soil is a rather soft solid that can be easily deformed (Fig. 1.1). Deformation of soil matters as it can lead to settlement and cracks in buildings. Even worse, inclined soil in slopes can move downhill. This motion can be either slow or fast. In the latter case we have catastrophic landslides that can cause thousands of casualties (Fig. 1.2). Landslides can also occur underwater. Gently inclined submarine slopes comprising thousands of cubic kilometres can suddenly start moving giving rise to mega-tsunamis (e.g. the prehistoric Storegga landslide in the North Atlantic). Thus, soil can behave as a fluid, despite its ability to permanently sustain shear stress. Also, horizontally layered soil, i.e. not inclined soil, can be suddenly transformed into a fluid. This is the case when a water-saturated loose sand deposit undergoes a sudden mechanical excitation (e.g. earthquake). The results are peculiar, buildings can sink into the liquefied sand. Sand can also fly (Fig. 1.3). Jet winds can carry thousands of tons of fine sand to heights of up to several kilometres and move it from, say, the Sahara to Europe. Wind is also responsible for the motion of sand dunes.

Exploiting the softness of soil, geotechnical engineers may intervene applying many operations to it. They undertake big excavations to build, e.g. underground garages, or to extract ore or lignite from the underground. They raise earth dams, which can be destroyed by internal erosion if not properly densified. They improve the bearing capacity of foundations by densification of the underground or by the installation of piles. They support cuts or fills in the underground by retaining walls, etc. For all this, one needs to understand the mechanical behaviour of soil and to this end a large variety of experiments have been carried out over the last decades. Being considerably softer than the usual solids (such as steel or concrete), soil samples allow large and complex deformation in the laboratory. They demonstrate a mechanical behaviour that appears extremely complex on first look. Knowledge of this behaviour however, opens the possibility to assess the deformation (i.e. behaviour under loading) and the stability of soil, and thus, preventing catastrophes such as landslides.

Figure 1.1 Footstep on the soil of the moon (NASA). The irreversible deformation of soil manifests its inelastic nature and also its memory. Soil, in particular sand, was the first material with memory exploited by mankind.

1.2 Granulates in Chemical Engineering

Soil is by far not the only granular material of technical relevance. Chemical engineering considers a vast amount of other granular materials such as flour, sugar, coffee beans and ground coffee, soya beans, cement, ore, pellets, etc., which are of high economic importance (Fig. 1.4). Their mechanical behaviour is dictated by their granular nature which is exactly the same as that of soil. Of technical importance is their storage and transportation, the first accomplished in silos. Here, their granular nature poses some difficulties, especially at the outlets of silos, which often get clogged. As for the transportation of granulates, various techniques have been invented, among them dense and dilute phase pneumatic conveying. These bear similarities with the motion of sand in moving dunes and by jet winds.

1.3 Can We Consider Granular Media as Continua?

Should one treat soil as a continuum or rather as a 'discrete' medium composed of individual particles? In the era of digitalisation, there is a tendency to discretise everything. Also, in soil mechanics too, an increasing number of researchers turn to the discrete approach, as the increasing power of computers allow one to consider grains in large numbers. The idea that grains are the truth, and continuum is merely a fiction is gaining traction. This is a deep ongoing philosophical question: what is truth and what is fiction? In physics, scientists are accustomed to accepting a dual approach to tiny corpuscles, considering them both particles and waves. The problem is thus reduced to which method is more appropriate. The advantages of the continuum approach become clear when we recall the saying that there are those unable to see the forest for the trees. In view of the progressing oblivion of

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Figure 1.2 Soil can flow: A mure has covered a vehicle. Courtesy Mag. G. Obwaller, Community Wald im Pinzgau.

the continuum mechanics approach, this book aims to help interested scholars gain insight into it. The biggest merit of continuum mechanics is to allow the application of the powerful tool of calculus.

1.4 Differences between Granulates and Other Solids

Contrary to metals and other solids, granulates have a nearly vanishing tensile strength. They only have shear strength, which is mainly of frictional nature, i.e. proportional to normal stress (see Chapter 9). The part of shear stress that is independent of normal stress is called cohesion. A lengthy dispute ensues in soil mechanics as to whether cohesion should be attributed to electromagnetic attraction between the individual grains (so-called true cohesion) or not [92]. There is no conclusive answer as yet, but the author concurs with Schofield [92] that there is (almost) no true cohesion, and that an apparent cohesion is mainly due to interlocking between grains (caution, 'interlocking' here means merely that the grains are toothed and not that they are interwoven). This interlocking causes dilatancy, giving rise to suction in water-saturated soil, such that in the end the strength by cohesion is also frictional.

The other important peculiarity of granulates is the large range of density variation. One and the same soil can be encountered, at the same pressure, in dense and loose state, the latter being a bad underground for foundations. i.e., there is no unique relation between pressure and density. In other words, the same density can prevail at different pressures. The pronounced variability of density gives rise

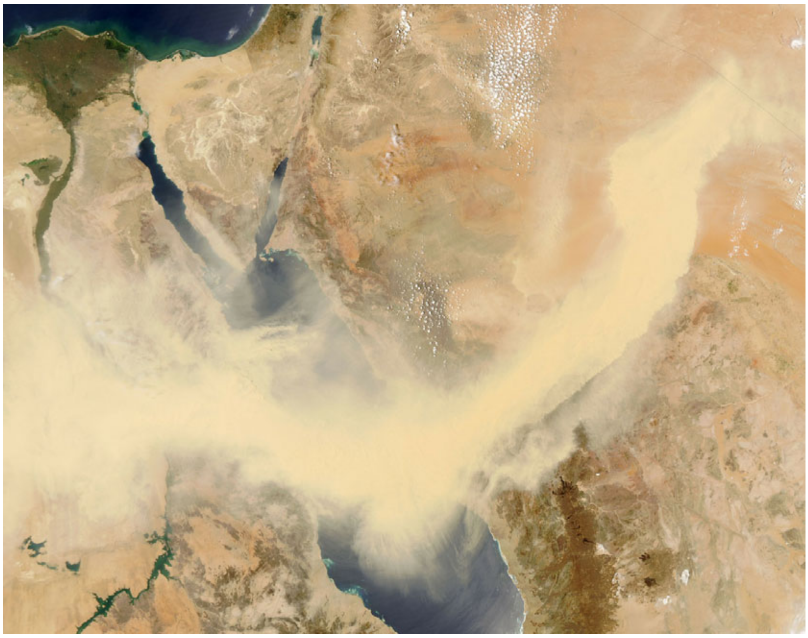

Figure 1.3 Soil can fly: Sand clouds over the Red Sea (NASA).

(a) (b)

Figure 1.4 There are many different granular materials, such as (a) spices and (b) gravel.

to the phenomena of dilatancy and contractancy with important implications for water-saturated sandy soil: vibrations can easily transform it into a liquid and this liquefaction is a feared side effect of earthquakes.

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