

1 Introduction

1.1 Introduction

In this chapter, we set the scene for the rest of the book. It may be helpful to remind readers of the relevance and importance of soil mechanics for all civil engineering construction: everything we construct sits on the ground in some way or other at some stage in its life. Even aircraft land on runways, and cars drive along roads; in each case there is some stiff layer (pavement) between the wheels and the prepared ground underneath. This stiff layer will help to spread the vehicular load but, in the end, this load must still be supported by the ground. Some examples of typical geotechnical design problems are presented in the next sections.

The term *soil mechanics* refers to the mechanical properties of soils; the term *geotechnical engineering* refers to the application of those mechanical properties to the design and construction of those parts of civil engineering systems which are concerned with the active or passive use of soils. Soils are the materials that we find in the ground: the term *ground engineering* is somewhat equivalent to *geotechnical engineering*. We will talk a little about the nature of soils in Chapter 3.

The term *soil* means different things to different people.¹ To an agricultural engineer, the soil is the upper layer of the ground which the farmer ploughs and harrows and in which crops are sown. To the civil engineer, this is the *topsoil*: it is recognised as valuable for agricultural purposes but usually too open in structure to be well suited for load bearing. Typically, the topsoil will be stripped from a construction site and stockpiled before serious construction activity begins. Underneath the topsoil is the soil with whose engineering properties we are concerned here. As we go further down into the ground, we will eventually encounter materials that no-one would have any hesitation in describing as *rock*. However, on the way there are many materials which can be described as hard soils or soft rocks: there is no precise

¹ Chambers' Dictionary defines *soil* as "the ground: the mould in which plants grow: the earth which nourishes plants" (from Latin *solum*, ground); but curiously *soil mechanics*, defined as "a branch of civil engineering concerned with the ability of different soils to withstand the use to which they are being put", is given as a sub-heading linked with Old French *souil*, wallowing place.

distinction and, although we are concerned primarily with soils in this book, much of what is presented will apply equally to weak rocks.

1.2 Soil mechanics

Soil mechanics is concerned with the mechanics of soils: a truism! It is an unfortunate feature of most civil engineering degree programmes that an atomistic approach to teaching is adopted: the teaching is broken down typically into structures, soils and water (with ancillary courses on mathematics, computing, and so on) and these subjects are developed in progressively greater detail through the three or four years of the degree with little opportunity being given to the embryonic engineers to integrate the separate elements and to recognise the importance of seeing the whole system as well as the parts. The whole may well combine elements that do not come from traditional civil engineering disciplines (mechanical or electrical, for example) and it is quite usual for systems to display emergent behaviours which had not been anticipated from the study of the constituent parts.

This book declares itself to be concerned with soil mechanics and therefore appears to perpetuate this segregation. However, opportunities will be taken where possible to demonstrate the behaviour of simple interactive systems: the interaction of soil with structural elements is a prime example where separate treatment of the different components is doomed to lead to erroneous expectations. But this book also attempts to integrate by addressing from a geotechnical point of view concepts which engineering students will be meeting as part of parallel courses on structures/materials or fluids/hydrostatics. Concepts of stress, stiffness, strength, fluid pressure, fluid flow and diffusion will, no doubt, be encountered in different contexts. The different treatments should not only indicate that there is a common thread of mechanics linking all aspects of engineering, but also encourage versatility and, further, provide reinforcement of learning.

1.3 Range of problems/applications

It is often said that the challenge of geotechnical engineering is that the soils have to be taken as they are found. Whereas structural materials such as steel and concrete can be designed to have particular desirable properties, the ground is as it is as a result of millennia of geological and geomorphological actions. The design of the geotechnical system will have to accommodate whatever properties the ground possesses. There may, on occasion, be some possibilities of modifying the *in-situ* properties of the ground to some extent. And where filling is required to build an embankment or a dam or to build up the ground behind a retaining wall, then it may be possible to consider this as a “designer soil”.

From the point of view of design or analysis, the usual starting point with a geotechnical problem is to ensure that failure will not occur. Such stability or *ultimate limit state* calculations are often reasonably straightforward – certainly by comparison with the possibly more significant calculations of displacements under

1.3 Range of problems/applications

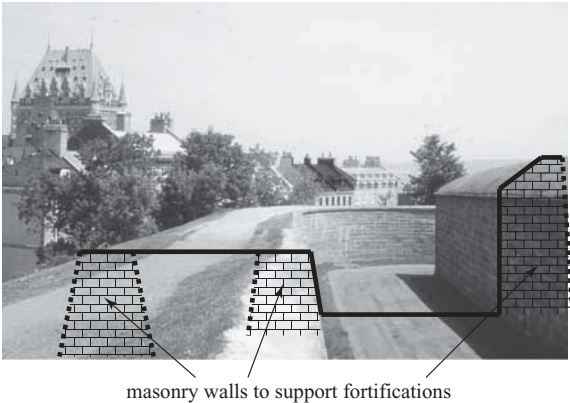


Figure 1.1. Military fortifications (Quebec City, Canada).

working conditions, the so-called *serviceability limit state* calculations. That there might be these two contrasting perspectives tells us that we will want to know about both strength and stiffness of soils – as of other materials.

Figures 1.1–1.13 show examples of geotechnical problems.

The design of military fortifications (Fig. 1.1) provided an important need to understand the way in which banks of earth could be supported by masonry walls. Coulomb, whose name is perhaps better known in the context of electrostatics, is known in soil mechanics as a pioneer of the practical analysis of earth pressure as a result of his experience in the design of fortifications for the French in Martinique in the eighteenth century. His challenge was to determine in a systematic way how large the masonry walls would need to be in order to guarantee the stability of the

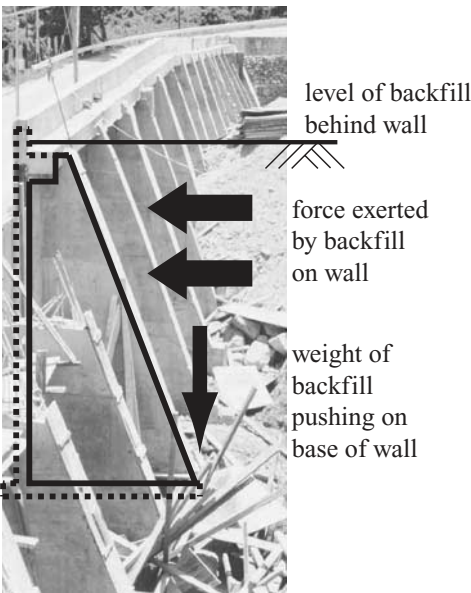


Figure 1.2. Retaining wall (New Territories, Hong Kong).

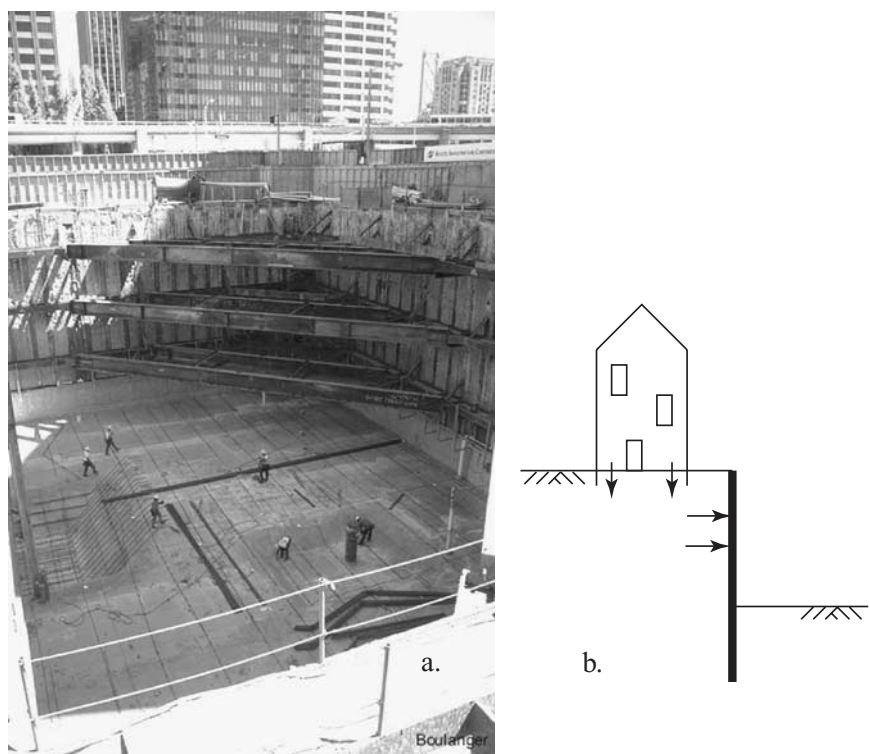


Figure 1.3. Deep excavation beside existing buildings (Century Hotel, San Francisco) (©Ross Boulanger).

ramparts. Nowadays retaining structures are often made of reinforced concrete and the shape of the wall can be chosen to make the supported soil – the *backfill* – help to stabilise the wall. The concrete cantilever retaining wall (Fig. 1.2) is being pushed over by the backfill, but the weight of the backfill is also pushing down on the base of wall and helping to stop the wall from overturning.

In congested urban areas, the value of land is so high that developers need to maximise the amount of space that they can generate and consequently build downwards as well as upwards. A deep excavation made beside existing buildings (Fig. 1.3) presents a more serious challenge of supporting the remaining ground in such a way that movements towards the excavated hole are kept small to avoid damage to the neighbouring structures. Tunnelling provides another means of exploiting underground space in cities for various sections of infrastructure – transport, drainage, services, flood relief (Fig. 1.4). Where tunnels are formed beneath existing buildings or near existing underground structures the deformations caused by ground loss during tunnelling must be kept small. The tunnel needs to be excavated and supported at the same time.

The retaining structures of Figs 1.1, 1.2, 1.3 are supporting the ground. Bridge structures rely on the ground for support. An arch bridge (Fig. 1.5) has to push laterally on the ground to generate the support for the dead and live load that it

1.3 Range of problems/applications

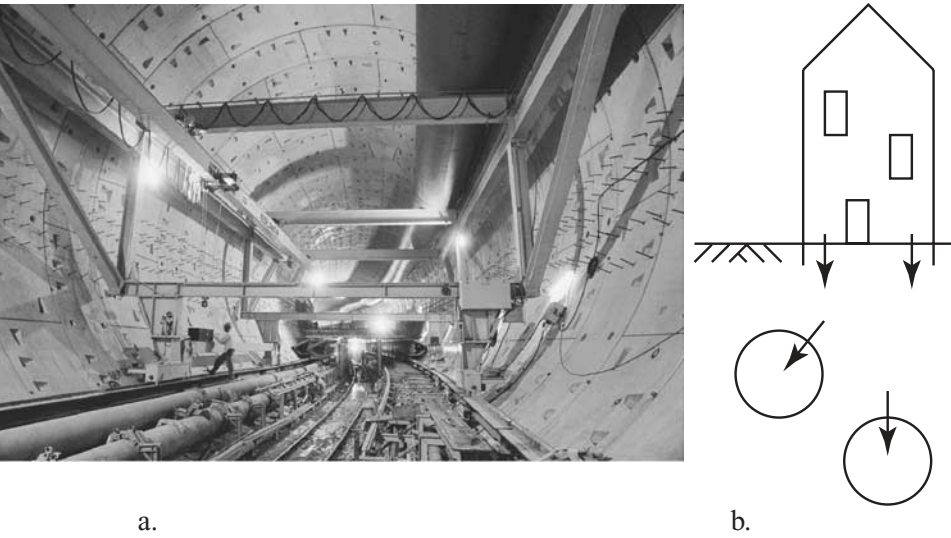


Figure 1.4. (a) Combined flood relief and road tunnel under construction (Kuala Lumpur, Malaysia) (©Mott MacDonald); (b) tunnelling beneath existing foundations.

carries: if the lateral push cannot be sustained then the bridge may deform in a way which is not comforting to the public. The bridge will expand and contract with seasonal variation of temperature and, as it expands, the supporting abutments will be pushed against the soil. What will be the forces on these abutments? We will need to design the structural elements to take account of the interaction between the abutment and the ground. Traffic on the roads will provide many repeated cycles

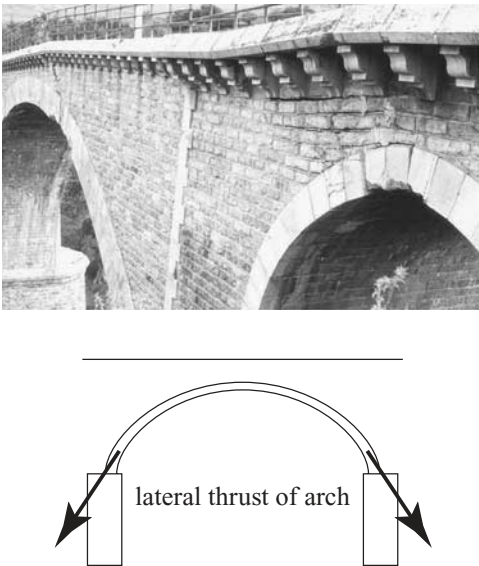


Figure 1.5. Arch bridge (Constantine, Algeria).

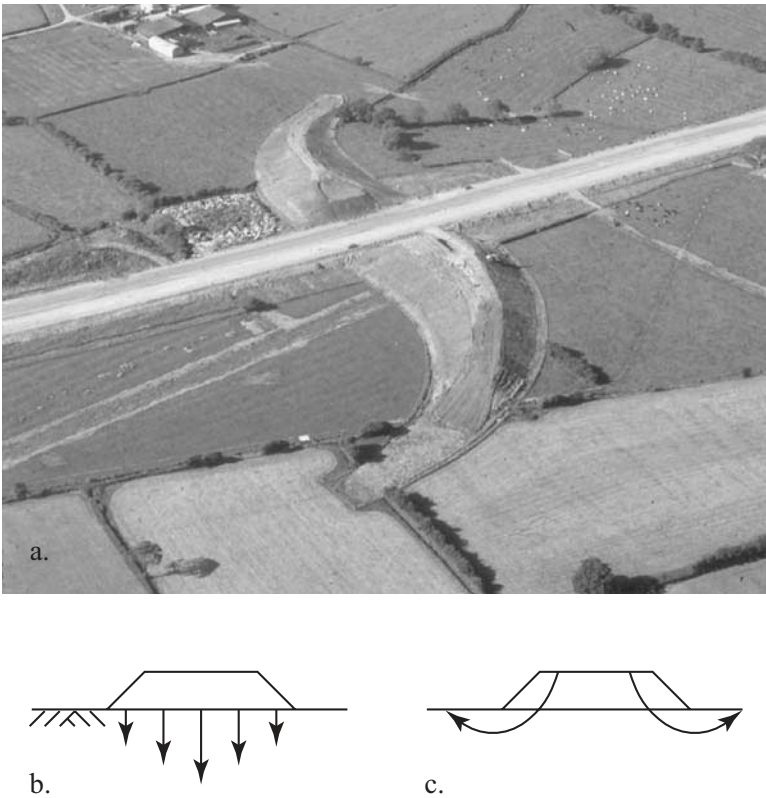


Figure 1.6. (a) Embankments on soft ground (M4 motorway and overbridge approach embankments, Bristol, UK) (©Sarah Dagostino); (b) settlement of embankment; (c) failure of side slopes of embankment.

of loading on the ground. The foundations of roads are usually engineered to ensure that the deformations of the road surface are tolerable.

On coastal or estuarine sites, it is often necessary to construct roads on soft ground, perhaps on man-made embankments (Fig. 1.6) to ensure that the road is above any likely level of inundation. Soft ground by definition is expected to show significant movements as it responds to the applied embankment load (Fig. 1.6b). It may not be possible to prevent such movements but they will need to be understood and managed in order to prevent failure of the embankment (Fig. 1.6c). Soft ground may not provide adequate support for shallow foundations (Fig. 1.7). The deformations may eventually become too much for the continued use of the building. A concrete platform for offshore oil production (Fig. 1.8) will eventually sit on the seabed and may store oil or water as ballast in integral concrete tanks; the deck provides operational and living quarters. The structure is subjected to all the power of the sea, which will try to overturn it or shift it sideways. Pile foundations (Fig. 1.9) are a means by which the loads from a highway structure can be taken deep into the ground away from other structures. By transferring the loads to firm soils or rocks

1.3 Range of problems/applications



Figure 1.7. Row of cottages founded on soft ground: (a) before (1973) and (b) after collapse/demolition of end cottage (1977). (Stanford Dingley, UK).

at depth the potential problems of settlement or failure of softer, near-surface soils (Figs 1.6, 1.7) are eliminated.

Vertical and horizontal shaking of the ground by an earthquake provides another form of loading which may need to be considered. Some sandy soils lose their strength as they are shaken and turn into quicksand as they liquefy – a seaside effect with which most children are familiar. The apartment blocks founded on such a soil at Niigata (Fig. 1.10) failed by rotation but remained largely structurally intact as they rotated.

In most of these examples, there will be concerns about the movements that may occur but in addition, in Figs 1.3, 1.4, 1.5 and 1.9, there will be concern about the consequences for the structural elements (retaining structure in Fig. 1.3; tunnel

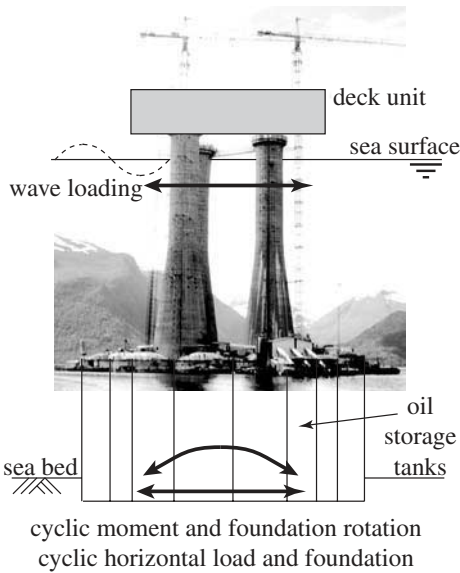


Figure 1.8. Concrete oil production platform under construction (Åndalsnes, Norway).

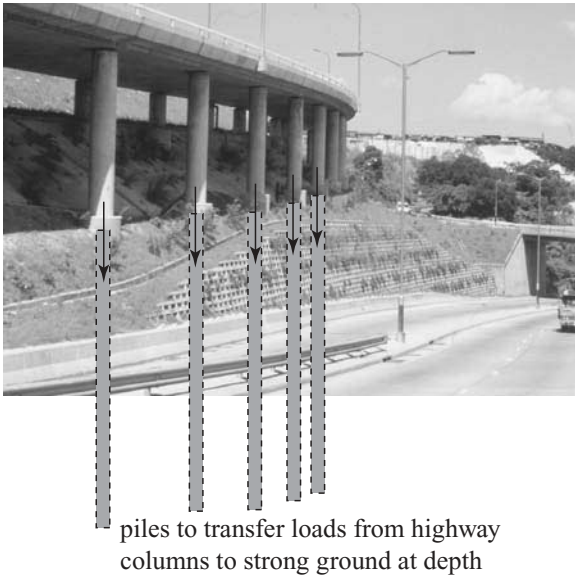


Figure 1.9. Highway structure founded on piles (Kowloon, Hong Kong).

or culvert linings in Fig. 1.4; bridge abutments in Fig. 1.5; pile foundations in Fig. 1.9; existing buildings in Figs 1.3, 1.4) of these movements. These are certainly examples where potential soil-structure interaction issues will need to be considered.

It will become clear that water plays an important part in the mechanics of soils and geotechnical engineering. It may be necessary to create dry excavations within or near a lake, river or sea protected by a cofferdam of driven sheet piles as sketched in Fig. 1.11a. Sheet piles are driven into the ground to form an enclosed space protecting the excavation from inflow of water and provide an environment



Figure 1.10. Failure of apartment blocks at Niigata, Japan as result of liquefaction induced by earthquake in 1964.

1.3 Range of problems/applications

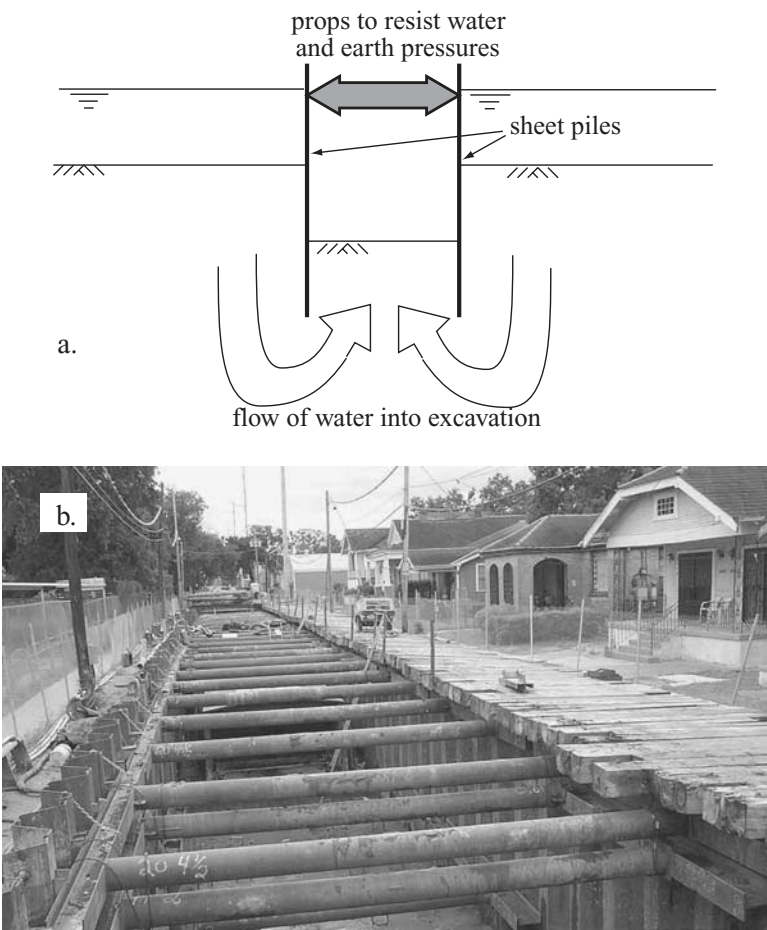


Figure 1.11. (a) Sheet pile cofferdam; (b) struts propping sheet pile walls to protect excavation.

within which the construction of the foundations for the pier of a bridge, or the laying of a pipeline, can proceed. The water and the soil around the piles will be pushing in: the forces must be resisted, for example, by props or struts near the top of the piles (Fig. 1.11b) – this is just another form of retaining structure. The control of the flow of water from the surroundings into the base of the excavation is a classic geotechnical design situation: pumps will be needed to keep it dry and we will need to be able to calculate the pumping capacity that is required.

An earth- or rock-fill dam may be used to form a reservoir (Figs 1.12 and 1.13). Such a dam is really just an enlarged and more sophisticated version of the hydraulic structures that we or our children build at the seaside. There is a core of some impermeable material providing a barrier, for example, clay (Fig. 1.12), or asphaltic concrete (Fig. 1.13). The core is intended to restrict the flow, but it may be impossible to eliminate leakage altogether. More permeable materials – graded crushed rock and rock-fill – are placed upstream and downstream as transition zones to

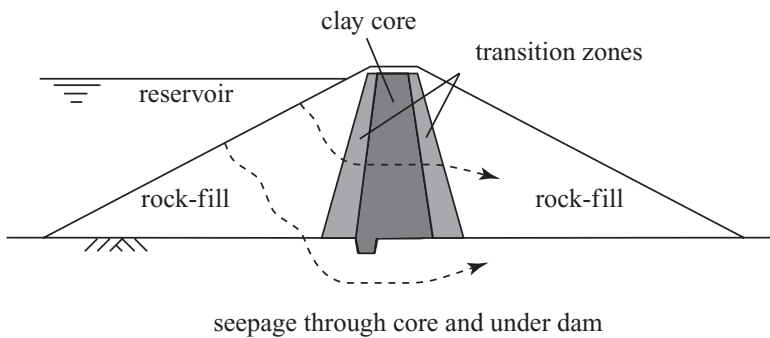


Figure 1.12. Rock-fill dam.

provide protection to the core, and discourage erosion. Such a geotechnical system is a quintessential application of “designer soils” where each of the zones of the dam will consist of soils chosen for their specific properties.

1.4 Scope of this book

A one-dimensional approach to these real-world problems involving soils may seem somewhat far-fetched but it will be seen that, for many of them, although the overall geometry is certainly three-dimensional, much of the detail of the mechanical

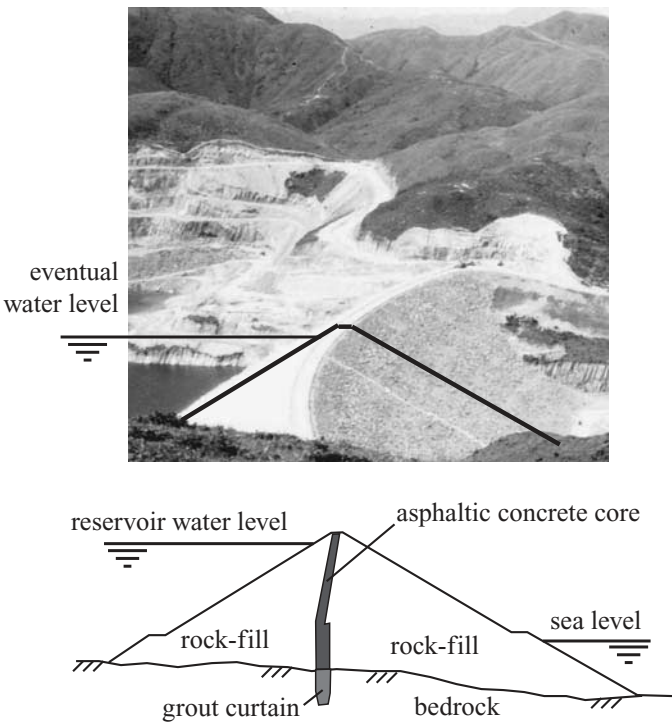


Figure 1.13. Dam with core of asphaltic concrete (High Island, Hong Kong).