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Environmental Geotechnics in Practice

Introduction and case studies

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Preface

For centuries, mankind has been dumping all manner of materials (both toxic and non-toxic) on land, usually in an uncontrolled manner. However, over the past 100 years the world has changed dramatically in terms of the size of its population, the amount of waste produced and dumped globally, rapid urbanisation, and the desirability or necessity of reusing land that has been affected adversely by former industrial usage. In response to these pressures, there have been developments in the technical aspects of geotechnical engineering to address environmental concerns and problems, as illustrated in the case studies contained within this book. This is the realm of environmental geotechnics, wherein construction involves significant actual, or potential, interaction between ground engineering and the environment.

The overall scope of the book is the past performance of landfills, land remediation works and waste tips and the effect of potential future scenarios. The case histories relate to sites in several different countries in Europe, America and Asia. These cases show mistakes that have occurred, successes that have been achieved, and how there has been a range of innovations in order to deal with a wide variety of problem sites in a safe and effective manner. It is believed that examination of the cases histories and awareness of the associated lessons can help current designers and constructers involved in environmental geotechnics to address problems that will be posed in the future and avoid system failures and environmental disasters. Specifically, the aims of this book include the following.

- Identify lessons to be learnt from past ‘geoenvironmental’ works to prevent mistakes that are foreseeable and avoidable in the future.
- Emphasise that any waste disposal facility, whether it be for municipal refuse, commercial waste or mineral spoil, should be properly engineered if negative impacts on the environment and society are to be avoided.
- Identify the key elements of a variety of geoenvironmental systems and explain each element’s role in protecting the environment.
- Demonstrate that it is possible to use geotechnical principles and practices to design suitable ways of disposing of waste and rehabilitating land damaged by waste dumping within a framework of a generic ‘source–pathway–target’ mechanism.
- Encourage readers not to apply a regimented formulaic approach to geoenvironmental practice and to critically appraise or assess the applicability of any design concept and data for the whole lifetime of a particular site, that is, during its construction, operational, closure and post-closure phases.

The initial part of the book contains a background to environmental geotechnics. The case histories have been chosen to cover technical issues associated with particular aspects of environmental geotechnics. Over half of the histories concern some form of ‘failure’ that promoted significant changes in geoenvironmental practice. The case histories are presented in chronological order because individual sites became larger and more complex with time and this caused more and more problems to arise. However, in general there was no true continuous ‘technological development’ of these facilities, that is, one cannot say that one change or development in disposal practice led to

Table 1.2 Waste materials generated in the UK (adapted from Defra, 2018)

Category	% of total waste
Mineral waste	39
Soil	27
Household and similar waste	10
Agricultural waste	9
Dredgings	6
Metallic waste	3
Vegetable waste	3
Paper and cardboard	1
Glass	1
Plastics	1

approximately 16 million m^3 of new tipping space each and every year. The waste situation is similar in most countries, although the actual amount of waste produced to be treated and disposed of depends on the state of development of a country and its waste management practices. Even incineration of refuse produces an end product, ash, which is generally disposed of in a landfill.

Until the late 1970s, there was little engineering input into landfilling practices and little concern over the effects of waste disposal on the environment. Landfilling operations commonly involved the uncontrolled infilling of natural depressions and man-made excavations. At that time, as Figure 1.6 shows, the infiltration of water into landfilled refuse and migration of polluted water (leachate) into groundwater was regarded as an integral part of the functioning of landfill sites. The underlying, implicit, principle at these sites was one of 'dilute and disperse'. This assumed that, within the groundwater, the concentrations of any contaminants derived from landfill would reduce to acceptable levels as they dispersed and were diluted under natural processes.

In the 1990s, landfill philosophy moved to the objective of total containment and isolation of wastes and there was a major upsurge in the development of engineered waste disposal by landfill. A landfill site consists of individual cells, which are filled and restored sequentially; waste is thus deposited within preconstructed containment areas. The waste is levelled and compacted to make maximum use of the available tipping space and to reduce impact from litter, flies, vermin, birds and fires. However, high placement densities tend to inhibit (and thus postpone) biodegradation. A thin layer of inert material or soil (daily cover) is placed on top of the refuse at the end of each day to prevent escape of windblown refuse, reduce odour emission, deter birds and vermin, and so on. If this layer is not broken up before filling recommences, high, perched, water tables may be created and landfill gas may move preferentially sideways.

As the number of 'holes in the ground' available for infilling dwindled, disposal practice moved from landfilling to landraising or landforming. However, the formation of hills of refuse, which will eventually undergo significant decomposition and settlement, incurs a number of disadvantages over landfilling and significant geotechnical input is required into the engineered construction of such waste disposal facilities.

It is estimated that, in the UK, the land area currently occupied by operating and closed landfills is approximately equivalent to the surface area of the county of Warwickshire (1975 km^2). This is a major legacy of buried refuse, which is likely to pose a variety of problems in the future, as outlined in Table 1.3.

Figure 1.6 Dilute and disperse concept

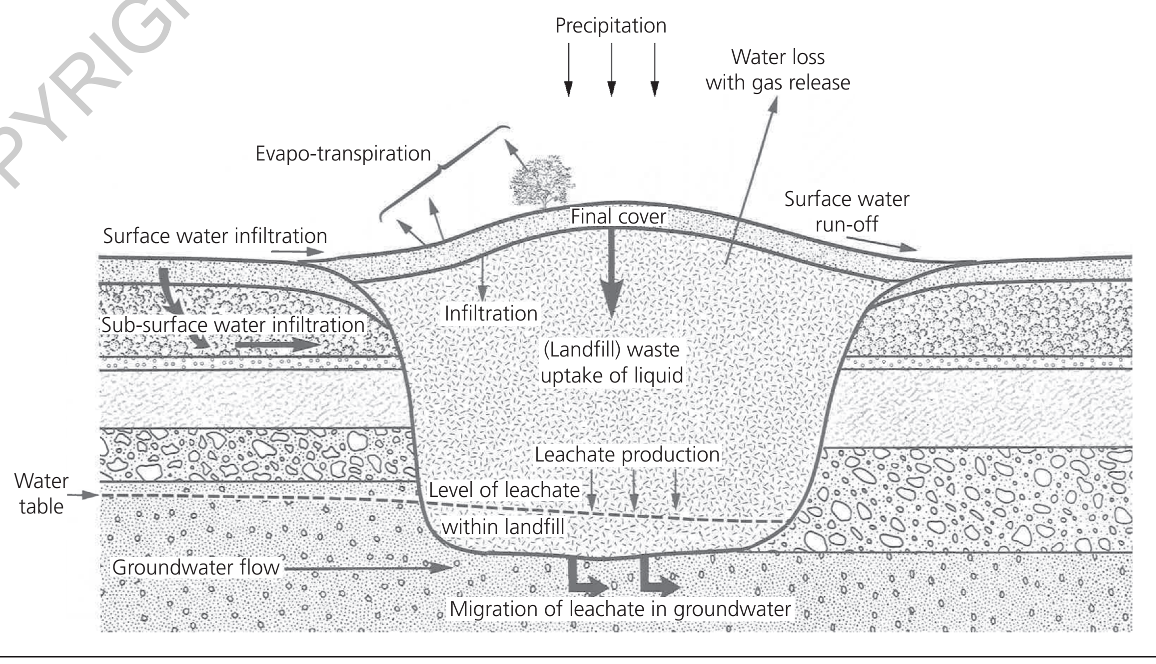


Figure 2.17 Local geology at Loscoe

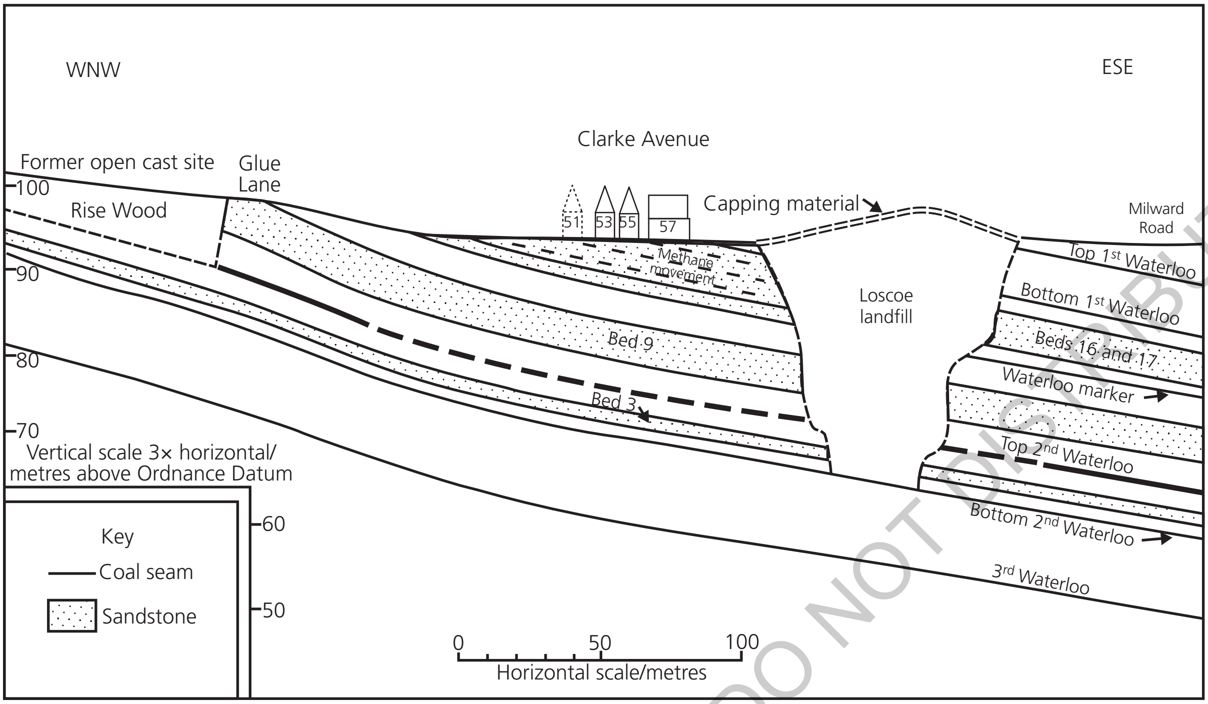


Figure 2.18 Quarry face that would become a wall of the Loscoe landfill site (from Williams and Aitkenhead, 1991)

supply, that is 3–4% by volume and with a methane: ethane ratio of about 25:1, and there was less than 0.5% carbon dioxide in the mains gas (as opposed to its high concentration in the soil).

The gas encountered in many of the monitoring points was generally similar to landfill gas (Table 2.10), but there was doubt about the potential transmission pathway from the landfill and thus the area likely to be at risk. To elucidate the source of the gas, carbon-dating was applied to the methane. Any carbon 14 (^{14}C) originally present in methane associated with coal of Carboniferous age (deposited approximately 350 million years ago) would have decayed to negligible concentrations by the time of the Loscoe explosion. Conversely, methane produced by biodegradation of recently dumped organic material would contain an amount of ^{14}C related to the present concentration in the atmosphere, which is relatively high. When the methane was analysed, it was found to contain concentrations of ^{14}C equivalent to about 1.25 times those found currently in the air, indicating that it was recently formed gas derived from a source such as a landfill and not the coal measures.

Despite the findings from the carbon-dating, there was a possibility that a small amount of gas was derived from the coal measures because the soil heating and distressed vegetation in gardens before the explosion could have resulted from the heat generated by a burning shallow coal seam. However, installation of a borehole in a garden showed a gradual decrease in soil temperature with depth and an increase in methane content of the ground gases from 2% at 0.5 m depth to 3.3% at 2.3 m depth and no coal was encountered. The reduction in temperature with depth and the absence of a coal seam was consistent with the theory that methane

Site history

In the early 1890s, William T Love hoped to generate cheap hydroelectric power by diverting water from the Niagara River through a canal around Niagara Falls before it would cascade down the Niagara escarpment. However, only a small portion of the canal (approximately 1.5 km long and 15–30 m wide) was actually excavated before the project was abandoned. The abandoned trench, which became known as the Love Canal, remained as a recreational area for swimming and boating well into the early twentieth century.[i]

In 1920, the Love Canal and surrounding land was acquired by Hooker Chemical for use as a municipal and chemical disposal site. The company did not install any liner to prevent pollution flowing from the site, but for nearly 30 years, the city of Niagara Falls, the US Army and Hooker Chemical dumped toxins, waste and household rubbish into the canal. For the period 1942 to 1953 alone, nearly 20 000 t of known and suspected carcinogenic chemicals (such as PCBs, trichloroethylene and residues from the manufacture of pesticides) were placed in the canal. In 1953, when the Love Canal was full, Hooker Chemical sealed it with a layer of well-compacted, stiff, low-permeability clay.

Shortly after closure of the dump, the Niagara Falls Board of Education purchased the site from Hooker Chemical and built an elementary school on a centrally located portion of the land. The Board sold the land not occupied by school buildings to private interests and, by 1966, residential development had eliminated all surface evidence of Love's excavation. By 1972, virtually all of the 99 houses on 97th and 99th Streets were completed – these would be subsequently referred to as the 'ring 1 houses' because their backs faced onto the closed landfill.

From autumn 1975 to spring 1976, the area experienced heavy precipitation; this resulted in unusually high local groundwater and subsidence of portions of the cover of the Love Canal landfill, which had been damaged by building activities. Rain and weathering released the buried chemicals from corroded steel drums and created ponds of heavily contaminated surface water, from which chemicals were washed into the basements of nearby residences.

During 1977 and 1978, state health officials monitored environmental contamination and found a high incidence of illness among children in the area. It was also noted that miscarriages and birth defects were common problems for families living in the Love Canal area. A study of families living alongside swales, which provided pathways for chemicals seeping away from the toxic canal, found that, for infants born during the period 1940–1978, there was a significant excess of low-birthweight babies when dumping was occurring (1940–1953). No such excess was evident for later years. In August 1978, the NYSHD declared a state of emergency at the Love Canal and ordered closure of 99th Street School and evacuation of pregnant women and children under two. A few days later, the US President approved emergency financial aid to allow New York State to buy the homes of 236 families located in Rings 1 and 2 (the so-called 'declaration area', Figure 3.11) and relocate families. These properties and the school on 99th Street were subsequently demolished. The year 1978 saw the start of approximately 20 years of working on pollution control measures at Love Canal.

The US Environmental Protection Agency (US EPA) was ordered to complete a comprehensive environmental study of the Declaration Area. As part of its programme, the US EPA reviewed all existing hydrogeological studies and undertook a comprehensive ground investigation to define the geology of the study area and to identify the direction and rate of movement of groundwater in the study area. A total of 248 different chemicals were identified, including benzene, carbon tetrachloride, polychlorinated biphenyls and trichlorophenol. Although works to control the escape of contaminants were undertaken over a period of years (Table 3.17), in 1988, after extensive testing, the Declaration Area was still declared uninhabitable by NYSHD. In 1990, when nine homes on the cleaned up edge of Love Canal went up for sale, there were widespread protests.

By autumn 1999, numerous remedial works had been completed (including landfill containment, leachate extraction and treatment, removal and disposal of contaminated sewer and creek sediments and other waste). These completed actions eliminated the significant contamination exposure pathways at the site, thereby making it safe for nearby citizens and the environment. In 2004, the site was deleted from US EPA's National Priorities List.

Figure 3.11 Properties around the Love Canal dump (showing the declaration area)

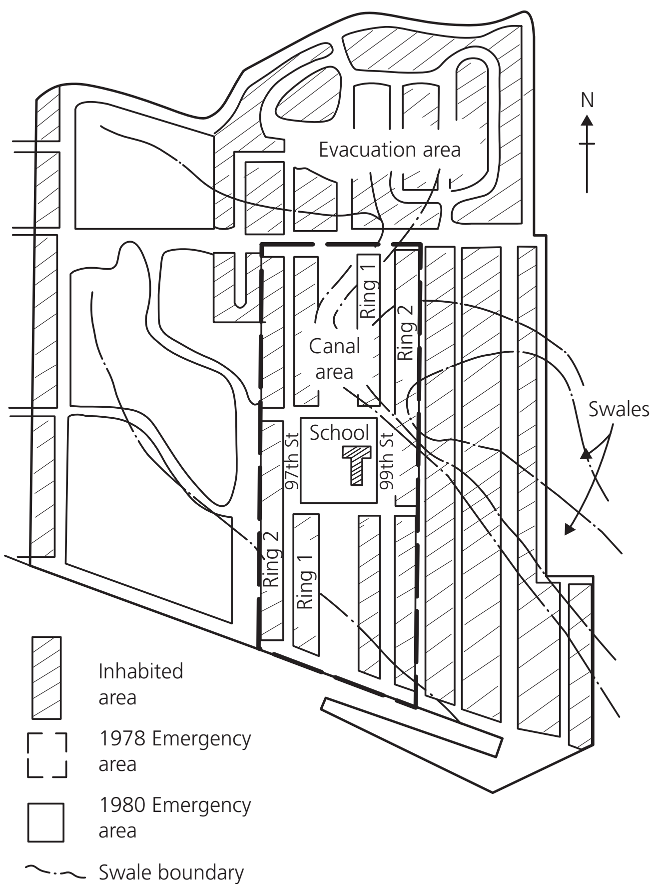
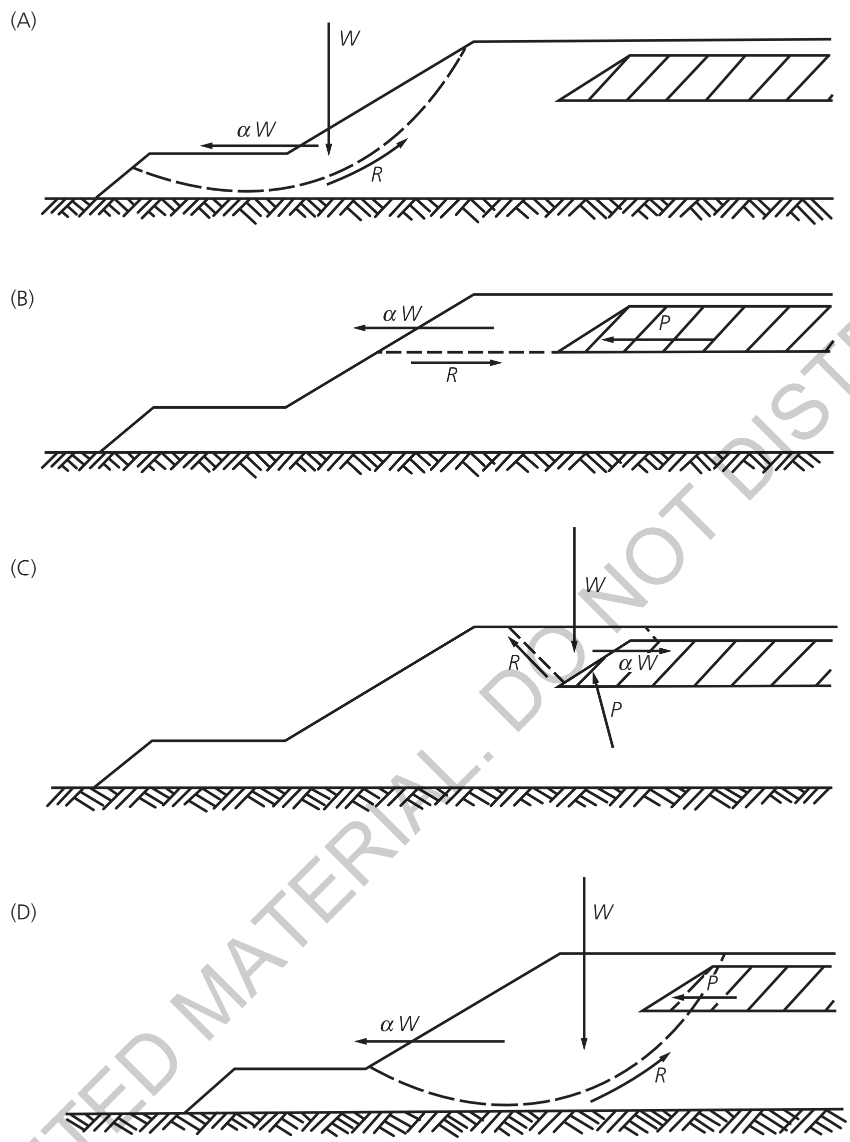


Figure 4.16 Possible failure mechanisms of the Old dam (Dobry and Alvarez (1967) with permission from ASCE)



Box 4.3 Possible failure mechanism of the El Cobre Old dam (see Figure 4.16)

Designation	Mechanism
A	The earthquake induces an initial shallow rotational failure in the front slope of the dam. This produces a scarp slope, which progresses backwards until it reaches the unconsolidated material in the slimes pond, at which stage the liquid tailings flow out
B	The liquefied tailings exert a lateral pressure, which is sufficient to cause outward sliding of a portion of the front slope of the dam so that the liquid waste can escape
C	The liquefied tailings exert a lateral pressure, which pushes a wedge of consolidated material up and outwards, so that the dam is overtopped. This causes the dam to fail so that the tailings can flow out
D	The lateral force from the liquefied tailings combines with the effect of the weight of the dam material to cause a deep-seated rational failure encompassing the dam and passing through the liquid tailings