PART I

BASIC PRINCIPLES

1

INTRODUCTION

1.1 EMERGENCE OF GEOENVIRONMENTAL ENGINEERING

Traditionally, geotechnical engineers have been responsible for (1) investigating subsurface conditions; (2) designing foundations for roads, buildings, machines, storage tanks, and offshore structures; (3) designing earthworks for dams, levees, roads, tunnels, and underground structures; and (4) investigating landmass problems such as landslides, slope stability, and subsidence (Taylor, 1948; Terzaghi and Peck, 1948; Lambe and Whitman, 1969; Peck et al., 1974). Geotechnical engineering was initially a loosely structured practice relying primarily on a few rules of thumb. After the 1950s, the practice of soil mechanics and foundation engineering grew tremendously throughout the world. The main contributors to this growth were Coulomb, Rankine, Darcy, Terzaghi, Casagrande, Taylor, Skempton, Bishop, and Peck. Through the work of these investigators, the practice of soil mechanics and foundation engineering became more rigorous, based on rational design approaches. As development of soil mechanics and foundation engineering continued, the practice of rock mechanics and engineering geology also evolved. Because all these topics proved interrelated, they were combined and renamed *geotechnical engineering* in the early 1980s. Since then, geotechnical engineering has developed into an important and necessary specialty of the civil engineering profession.

Simultaneous with the growth of geotechnical engineering, the post–World War II economic boom of the 1950s led to rapid industrialization. In particular, chemical industries grew in number and increased the standard of living by producing a wide variety of products. Manufacture of these products required the production of tremendous amounts of organic chemicals while increasing the use of heavy metals. Mass production of these products also increased the quantity of wastes to be disposed of. Improper disposal practices and accidental spills of these chemicals have created numerous contaminated sites in the United States and throughout the world.

The onset of nuclear power plants and nuclear waste generated awareness of contamination problems and perhaps initiated the involvement of geotechnical engineers in environmental matters (Daniel, 1993). According to the National Environmental Policy Act of 1970, environmental impact assessments were required for any federal project that could affect the environment, particularly those involving the selection of nuclear power plant sites. Geotechnical engineers lead the detailed site investigations for these impact assessments. Another concern was the ultimate disposal of high-level radioactive waste, which can remain lethal for thousands of years. Geotechnical engineers played an important role in the investigation and characterization of suitable host soil and rocks for waste repositories. Geotechnical engineers also determined long-term performance of earth materials under realistic temperature and pressure, probable groundwater impacts, and potential risks. With increased attention, environmental concerns became a new aspect of geotechnical engineering.

One specific environmental event that increased attention was the widely publicized contamination at Love Canal in upstate New York. At this site, chemical wastes were buried in an old canal and covered with clayey soils. The chemicals seeped out slowly, contaminating the soil and groundwater. The health of the residents was adversely affected and the entire area had to be evacuated. This incident drew national attention to the effects of improper disposal and management of chemical waste. As a result, in the late 1970s and early 1980s, discussions began on the prevention and mitigation of such improper waste disposal practices. Also, as a result of this incident, new U.S. regulations for remediation of contaminated sites, in addition to the design of effective waste containment systems for newly created wastes, were promulgated. In 1970, the Resource Conservation and Recovery Act (RCRA) and its subsequent amendments addressed issues of disposal of newly generated waste. In 1980, the U.S. Congress passed the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), also known as the Superfund, to clean up contaminated sites in cases where the responsible polluting parties could not be identified or were incapable of paying for the cleanup. The geotechnical engineer's knowledge of earth material and groundwater became vital to the investigation, design, and actual cleanup of contaminated sites as well as the design of containment facilities.

Waste containment and remediation problems require an understanding of the physical characteristics of the subsurface and the ability to engineer it using the skills of classical geotechnical engineering. However, these problems also require an understanding of the chemical characteristics of the subsurface and the ability to engineer pollution control or removal using the skills of environmental engineering. A combined expertise of geotechnical engineering and environmental engineering is needed to address various aspects of such problems. In addition, knowledge of environmental regulations, hydrogeology, environmental chemistry, geochemistry, and microbiology is needed. Recognizing this fact, a new specialty of civil engineering known as *geoenvironmental engineering* (also known as *environmental geotechnology* and *environmental geotechnics*) emerged in the early 1990s. Geoenvironmental engineering encompasses the behavior of soils, rocks, and groundwater when they interact with contaminants and addresses problems of hazardous and nonhazardous waste management and contaminated sites.

Geoenvironmental engineering is evolving rapidly. Environmental laws and regulations that have a significant impact on geoenvironmental engineering are constantly changing. Environmental problems are numerous in all industrial and developing countries and will continue to grow with increased chemical waste generation and handling. For these reasons, geoenvironmental engineers will play a vital role in pollution control strategies, particularly in the design of effective and economical waste containment and remediation systems.

1.2 TYPES OF GEOENVIRONMENTAL PROBLEMS

Geoenvironmental problems may be grouped into three categories:

1. *Contaminated site remediation:* remediation of already contaminated soils and groundwater using in-situ barriers and in-situ or ex-situ treatment methods
2. *Waste containment:* safe disposal of newly generated wastes in engineered impoundments and landfills
3. *Waste minimization by recycling:* minimization of waste generation and disposal by recycling and using waste materials in various civil engineering applications, and beneficial use of closed waste disposal sites

A general overview of these problems with examples is provided in this section.

1.2.1 Contaminated Site Remediation

Until the early 1970s, environmental laws and regulations did not exist; therefore, chemicals were used and wastes were disposed of without proper consideration of potential impacts on public health and the environment. As a result, numerous sites have been contaminated by toxic chemicals. The U.S. Environmental Protection Agency (USEPA) estimated in 1997 that over 200,000 contaminated sites, where toxic chemicals pose unacceptable risk to public health and the environment exist in the United States.

The Wide Beach development site in Brant, New York, a 55-acre lakeside community development, is an example of contamination resulting from improper use of chemicals (USEPA, 1998b). From 1964 until 1978, waste oil containing polychlorinated biphenyls (PCBs) was applied to roadways in the community to control dust. In 1980, during the installation of a 1-mile sanitary sewer trench, soil from the roadways was excavated and used as fill in several residential yards. An odor complaint in the community led the regulators to discover drums containing waste oil with PCBs. Further investigation revealed that PCBs were present in soils from roadways and residential yards, in vacuum cleaner dust from residential homes, and in water from residential wells. An extensive remedial action, including the removal of drums and treatment of contaminated soils, cost more than $15 million.

The highly publicized Love Canal site, located in Love Canal near Niagara Falls in New York, demonstrated the consequences of improper disposal of wastes (*www.usepa.gov*). Between 1942 and 1953, over 20,000 tons of chemical waste was disposed of in an abandoned canal by a chemical manufacturing company. In 1953, the Niagara school board bought the property, despite a warning regarding the chemical waste present. A school was built and opened in 1955, with some buildings atop the waste-filled canal. By 1972, several homes with basements were built surrounding the school. In 1976, heavy rainfall in the area caused groundwater to rise. This rise caused subsidence of the waste-fill area, resulting in contamination of surface water. In addition, seepage of groundwater transported toxic chemicals into the basements of the surrounding homes. When children in the area fell sick in 1977 and 1978, the contamination was discovered. The Love Canal site was then evacuated and a state of emergency was declared. This incident drew national attention, initiating many environmental laws and regulations. Extensive remedial action at this site has been undertaken, at a total cost exceeding $200 million.

In addition to site contamination resulting from improper chemical use or waste disposal practices, spillage of toxic chemicals during handling, transportation, and storage have polluted soils and groundwater. Leaking underground storage tanks that contain petroleum products and other toxic chemicals are common occurrences. In 1995, the USEPA estimated that there are over 400,000 sites where soils and groundwater have been contaminated by leaking underground storage tanks. An example of such sites is the Fairfield Semiconductor Corporation site in San Jose, California, which operated from 1977 until its closure in1983 (USEPA, 1998c). In 1981, an underground storage tank containing organic solvents failed, resulting in both soil and groundwater contamination by a mixture of solvents. An estimated 60,000 gal of waste solvents was released. Extensive remedial action was necessary, including removal of tanks, installation of slurry walls around the site perimeter to contain contaminated groundwater, extraction of contaminated groundwater, and treatment of contaminated soils. The remedial cost was over $4 million.

The role of geoenvironmental engineers in the remediation of contaminated sites, especially in dealing with contaminated soil and groundwater, is critical. Knowledge of soil composition, soil stratigraphy, groundwater hydraulics, and geochemistry can be applied to assess, develop, and implement effective remedial methods. In particular, geoenvironmental engineers have the capacity to lead subsurface investigations for the design of in-situ remedial strategies.

1.2.2 Waste Containment

Wastes are created that require disposal despite the best waste management practices. Such wastes include household garbage, mine refuse, highly toxic industrial by-products, and nuclear wastes. Proper disposal of these wastes in engineered waste containment facilities is crucial to protect public health and the environment.

Containment facilities for liquid wastes are known as *surface impoundments,* or more commonly, *lagoons* and *ponds.* These impoundments have to be lined properly at the bottom to prevent infiltration into the subsurface of their chemical constituents. In the past, because regulations on such linings did not exist, linings were not provided, resulting in several contaminated sites. An example of such a site is the Anderson Development Company (ADC) site in Adrian, Michigan (USEPA, 1998a). The ADC occupied approximately 12.5 acres of land, surrounded by residential areas. Between 1970 and 1979, the site was used for the manufacture of 4,4-methyl-bis(2-chloroamile) (MBOCA), a hardening agent used in plastics manufacturing. Process wastewaters were discharged to an unlined 0.5-acre lagoon. Later, contamination was found in the soils surrounding the lagoon. Because of the potential health hazard, the lagoon was closed and the contaminated soil was treated. Approximately $2.7 million was spent for completion of this project.

Containment facilities for solid wastes are known as *landfills*. In the early 1970s, wastes were disposed of in open ditches or pits, or piled above the ground surface. With no lining at the bottom, such disposal practices led to several contaminated sites. For instance, at a southern Illinois coal mine, liquid waste impoundments from coal processing were created within massive surface piles of coarse tailings (Reddy and Schuh, 1994). Waste constituents from the piles and impoundments have infiltrated the subsurface, causing groundwater pollution. A community in close proximity to the site drew the groundwater for drinking purposes. Because of the public health concerns, control of contamination at the source and the cleanup of groundwater became necessary, and remedial action, which includes closing the piles and impoundments and implementing remedial action, is expected to cost over $1 million.

Several Army bases also reportedly contain numerous unlined pits where toxic chemical wastes have been dumped, and soil and groundwater contamination has occurred as a result. For instance, at McClellan Air Force Base (AFB) near Sacramento, California, fuel and solvents were disposed of in several pits from the early 1940s until the mid-1970s (USEPA, 1998a,c). Later, an impermeable cap was constructed over the pits to reduce rainwater infiltration and subsequent leaching of contaminants into the groundwater. However, contaminants seeped out of the pits, contaminating the soil as well as the groundwater more than 100 ft below the ground surface. Corrective action involving groundwater treatment and soil remediation cost exceeded $3.8 million.

Newly generated liquid and solid wastes are required to be disposed of in engineered impoundments and landfills. All these containment facilities require liner systems that perform as both hydraulic and chemical barriers. In addition, these facilities must be located where hydrogeologic conditions are favorable. Upon reaching their waste storage capacity, the containment facilities should be covered properly to isolate the waste and to prevent infiltration of precipitation. The mechanical stability of liner and cover systems should also be ensured. The role of geoenvironmental engineers is crucial in the selection of a suitable site for locating waste containment facilities as well as for the design and construction of liner and cover systems for effective containment of wastes.

1.2.3 Waste Minimization by Recycling

During the past few years, intense efforts have been made to prevent or at least minimize generation of wastes through the use of environmentally benign materials and innovative manufacturing processes. Recycling efforts have been increased to divert wastes from disposal in containment facilities. The recycled materials include domestic wastes such as paper, plastics, glass, and tires, as well as industrial wastes such as fly ash and bottom ash. Recycling efforts have been fairly successful, and large quantities of materials have been collected. However, except for paper, markets that can utilize such materials are limited or can consume only minimal quantities. Therefore, new applications that have potential to consume large quantities of recycled materials are urgently sought. Large-scale beneficial use of recycled and waste materials is possible for civil engineering applications. In addition, in several cases, closed waste containment sites have been used for recreational, industrial, and commercial purposes, such as parks, golf courses, and buildings.

Geoenvironmental engineers are involved in evaluating the feasibility of using recycled materials as soil substitutes in various large-scale civil engineering applications, including roadways, embankments, and retaining structures. In addition, large-scale environmental engineering use of recycled and waste materials, including soil substitutes in the design of waste containment systems and reactive media substitute in soil and groundwater remediation systems, is growing rapidly. These applications involve evaluation not only of their mechanical properties and behavior, but also environmental aspects, including chemical compatibility and durability.

1.3 BOOK ORGANIZATION

The book is divided into four parts:

- Part I: Basic Principles
- Part II: Remediation Technologies
- Part III: Landfills and Surface Impoundments
- Part IV: Emerging Technologies

Background on environmental regulations, inorganic and organic chemistry, soil composition and properties, geochemistry, groundwater, and contaminant fate and transport, all essential to an understanding of geoenvironmental problems, are covered in Part I. In Part II, assessment and remediation of contaminated sites are presented, including a general overview of sources of subsurface contamination, methods to characterize the contaminated sites, methods to quantify the risk posed by the site contamination, and various remedial methods: in-situ barriers, soil remediation technologies, and groundwater remediation technologies. In Part III, waste characterization and waste containment systems are described. Various sources and types of wastes and their properties are described first. Siting, permitting and design of landfills are then described. Finally, design of surface impoundments is discussed. In Part IV, several different emerging waste management technologies are described, including waste material recycling, end use of closed landfills, bioreactor landfills, and subaqueous sediment containment.

1.4 SUMMARY

Originally, geotechnical engineering was a loosely designed discipline focused primarily on the use of earth materials and the roles they play in construction. Since the 1950s, however, geotechnical engineering has undergone a tremendous amount of growth. A shift in job involvement began to occur in the 1970s as a series of high-profile environmental disasters occurred, leading to increased public awareness. As environmental problems have become more prevalent, geotechnical engineers have played an increasing role in finding solutions. Geoenvironmental engineering has evolved by utilizing combined geotechnical and environmental engineering technologies to address the problems of contaminated sites as well as hazardous and nonhazardous waste management. This new field of engineering is evolving rapidly, due to changed regulations and advanced knowledge through research and innovative practice methods. In this book we present the current state of practice in geoenvironmental engineering.

QUESTIONS/PROBLEMS

1.1. Name and briefly discuss three notable incidents that have had an adverse impact on the environment in the past 50 years.

1.2. How do geotechnical engineering and geoenvironmental engineering differ?

1.3. Discuss briefly how accidental releases of hazardous chemicals into the subsurface would affect the environment. How may an engineer prevent releases by containment facilities?

1.4. Why are geoenvironmental engineers uniquely qualified to address subsurface contamination problems?

1.5. Discuss how recycled materials may be used in engineering projects. Discuss why it would be important to analyze the engineering properties of such materials.

1.6. A former unlined landfill that accepted municipal and industrial waste is located 500 ft from a drinking water well in a rural town in Illinois. Investigation indicated the presence of benzene and lead in groundwater immediately downgrade of the landfill, and the groundwater plume is found to migrate in the direction of the drinking water well in the town. A potential remedial strategy considered in this situation includes (1) capping the landfill, (2) installing a leachate collection system, (3) constructing an impermeable slurry wall, (4) installing a groundwater extraction well system, (5) air stripping of extracted leachate and groundwater, and (6) discharge of treated leachate and groundwater to nearby streams. Identify various geoenvironmental engineering issues and/or tasks involved in this project. Explain them briefly.

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