ENVIRONMENTAL IMPACT IN GEOTECHNICAL ENGINEERING

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Environmental impact in geotechnical engineering
Impact environmental et génie géotechnique

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SYNOPSIS: The impact of the environment on civilization is the subject of the International Decade for Natural Hazard Reduction (IDNHR). The IDNHR is sponsored by the United Nations and begins in 1990. Its primary goal is to mitigate the consequences of natural disasters such as earthquakes, tsunamis, landslides, etc. Concurrently, the impact of civilization on the environment is the subject of the World Commission on Environment and Development (WCED), also sponsored by the United Nations. The WCED has concluded that the global economy and the global ecology are now interwoven and interdependent. According to the WCED, disasters that appear to be isolated, such as Bhopal and Chernobyl, are the result of mismanagement of the global economy and ecology.

The impact of humankind on the environment is the primary subject of the present report. The current technical and legal trends in America, Brasil, and Southeast Asia are summarized. It is concluded that geotechnical engineers will continue to be very involved in developing solutions to natural hazards. On the other hand, landfilling of municipal, industrial, and hazardous wastes is probably a temporary solution, in spite of great advances in containment technology. In the future, these wastes will likely be reduced, recycled, incinerated, or chemically stabilized. Consequently, geotechnical engineers will have less and less to do with these wastes as mechanical and chemical engineers develop alternative solutions.

1 INTRODUCTION

The ISSMFE first explicitly considered the interrelationship between geotechnical engineering and the environment at a specialty session at the 9th ICSMFE in Tokyo (Moh, 1977a). The Proceedings of this session, including thirty-two papers, panel presentations, and other written contributions, were published separately in two volumes (Moh, 1977b; 1978).

Subsequently, the following major events have occurred regarding this topic:

1. A session on environmental geotechnics and a state-of-the-art report were included in the 10th ICSMFE in Stockholm (Sembenelli and Ueshita, 1981a,b).

2. A session on geotechnical aspects of environmental control and a theme lecture were included in the 11th ICSMFE in San Francisco (Morgenstern, 1985).

3. An International Symposium on Environmental Geotechnology was held in Allentown, Pennsylvania, USA, under the auspices of Lehigh University and the International Committee on Environmental Geotechnology (Fang, 1986, 1987).

4. A Technical Committee on Environmental Control and Waste Disposal was formed by the ISSMFE in 1987, chaired by Z.C. Moh. This technical committee is sponsored by the Southeast Asian Geotechnical Society, and is one of over 20 formed by the ISSMFE.

This brings us to the 12th ICSMFE in Rio, which includes this special lecture, and a discussion session on Environmental Control and Waste Disposal. The discussion session includes reports from three subcommittees regarding Definition of Environmental Geotechnics, Codes and Standards, and Bibliography.

In the two previous state-of-the-art reports by Sembenelli and Ueshita (1981a) and Morgenstern (1985), the authors struggled to classify environmental geotechnology and to define the role of the geotechnical engineer in this field. We have preserved this tradition (of struggle), partly because the field is so diverse and vague, and partly because the role of the geotechnical engineer continues to change. Sembenelli and Ueshita were more philosophical and covered a broad range of topics; whereas, Morgenstern was more incisive and discussed three technical subjects in detail. Our report is a mixture of these two approaches. Section 2.0 is somewhat philosophical, and discusses natural environmental impacts vs. man-made. Sections 3.0, 4.0, and 5.0 are more technical, and present the American, Brasilian, and Southeast Asian perspectives, respectively.

But first, we felt it would be beneficial to update some of the important points presented in the two earlier state-of-the-art reports:

Sembenelli and Ueshita: 10th UCSMFE, Stockholm (1981)

1. **Better geotechnical maps are needed.**

The Personal Computer revolution has created a new type of software, generically called Geographic Information System (GIS). Various GIS's are available, which can be used for the electronic storage, transmittal, and sharing of geotechnical information.

A recent conference on this subject was GIS '87 - San Francisco.

2. Greater international cooperation regarding environmental geotechnics is needed, under the auspices of the ISSMFE.

In Section 2.2.4, we recommend that the ISSMFE develop model geotechnical codes for environmental protection. As noted above, a report on codes and standards is also included in the discussion session on Environmental Control and Waste Disposal at this conference in Rio.

3. Mine tailings are among the most intractable and environmentally harmful, especially phosphatic clay.

In 1981, phosphatic clay was ranked by the Organization for Economic Cooperation and Development (OCED) as having no potential for re-use. Since then, great progress has been made: many thousands of hectares in Florida have been reclaimed to a semi-natural condition (Bromwell and Carrier, 1983; Ericson et al., 1984; Ericson and Mills, 1986), and recent research indicates that the clay can be used for agriculture (Gonzalez and Sartain, 1986; Sartain et al., 1987; Million, et al., 1987; Stricker et al., 1988), or for housing and light industrial structures (Madrid and Carrier, 1987). The success with phosphatic clay suggests that other mine tailings may be re-used also (de Mello and Carrier, 1987; Carrier et al., 1987).

4. Safe disposal of radioactive wastes is critical.

This topic is so controversial, and the subject of so many conferences, that we decided to exclude it from this report. But it is worth noting that in the 1981 Sembenelli and Ueshita report, Sweden was identified as having taken the lead in studying ways to dispose of spent nuclear fuels. Today, as a result of a national referendum, Sweden has decided to decommission all twelve of its nuclear power plants, representing half of its electrical supply, by 2010 (Kapstein et al., 1988).

5. Bibliography of Environmental Geotechnics is needed.

Sembenelli and Ueshita presented a list of references in their report that is nearly 30 pages long. The Technical Committee on Environmental Control and Waste Disposal is continuing this important work and, as noted above, a report is included in the discussion session at this conference.

Morgenstern: 11th ICSMFE, San Francisco (1985)

1. Synthetic membranes are challenging clay for use as impervious liners in hazardous waste landfills.

Both materials are now required in the United States, with plastic as the primary barrier and clay as a backup. In fact, the USEPA currently requires not one, but two liners and two leachate collection systems (see Section 3.1.1). Moreover, the liner design has become so codified that some legal authorities believe that strict liability applies. Recent conferences that addressed this subject were: (1) Third International Conference on Geotextiles (1986); (2) Geotechnical Practice for Waste Disposal '87; and (3) Symposium de Barragens de Rejeitos e Disposicao de Residuos Industriais e de Mineracao (1987).

2. Groundwater transport of contaminants and geochemical reactions in pollution barriers is the subject of much research.

This continues to be the case; recent conferences include: (1) Geotechnical Practice for Waste Disposal '87; (2) Hydraulic Barriers in Soil and Rock (1984); and (3) Symposium de Barragens de Rejeitos e Disposicao de Residuos Industriais e de Mineracao (1987). (Also see Section 3.1.2.)

3. Design and construction of tailings dams for the mining industry requires significant geotechnical input.

Tailings dams serve a dual function: (1) Clarification and storage of water for the milling operations; and (2) Storage and disposal of the waste mineral solids. Some mines are now finding that their operations can be simplified if these two functions are separated: First, the dilute tailings are deposited in a permanent reservoir near the plant; Second, the tailings are allowed to densify and the clarified water is recycled to the plant; Third, the thickened tailings are dredged and pumped to a separate disposal/reclamation area. After start-up, as much tailings are removed from the permanent reservoir as are deposited, and the water storage volume remains constant. This new system results in cost-savings associated with the water-return to the plant, the construction of the tailings disposal areas, and the reclamation of the tailings. See Section 4.3.2 for more details.

Usually, methods of tailings disposal are developed by the miners and the geotechnical engineers come along later to analyze and refine the methods. This is one of the few cases where the technology was created by the geotechnical engineers and adopted by the miners.

4. The upstream method of tailings dam construction involves depositing coarse material ("shell") over fine material ("slimes") and therefore requires special care.

Mittal and Morgenstern (1977) found that an upstream tailings dam should be satisfactory when the following conditions are met: relatively coarse tailings (less than 50% passing a No. 200 sieve); slow rate of raising (2-3 m/yr); and pervious foundation. This has become an oft-quoted rule-of-thumb. It is now known that the rate of raising is dependent on the compressibility and permeability of the slimes. In addition, the beneficial effect of the pervious foundation decreases as the height of the tailings increases. Hence, the rate of raising decreases with tailings height, regardless of the material properties of the slimes.

Furthermore, recent litigation concerning failures of two upstream tailings dams has exposed deep divisions within the geotechnical community regarding the correct method of slope stability analysis for these structures, and in particular, which shear strength to use. Some geotechnical engineers use drained shear strength and others use undrained shear strength. In the first camp, the effective stress is calculated based on hydrostatic pore pressures. The actual pore pressures are known to be less than hydrostatic (because of the pervious foundation), but using the actual pore pressures leads to a higher effective stress and therefore a greater resistance to shear. This in turn yields a slope design that is obviously too steep and consequently unsafe. Hence, in order to be conservative, the higher hydrostatic pore pressures are used instead. This approach has led to situations in which the effective friction angle of the slimes is greater than that of the shell, i.e., that it is the slimes holding up the shell and not the other way around.

In the second camp, the undrained shear strength is calculated based on a sophisticated prediction of consolidation during staged construction. Measured pore pressures are used to confirm the consolidation analyses, and laboratory tests are used to establish the ratio of undrained strength to effective consolidation stress ($S_u/\bar{\sigma}$). The variation in undrained shear strength is then evaluated laterally and vertically within the slope at each stage, and the slope stability is calculated accordingly.

The latter approach was advocated by Ladd (1988) in his Terzaghi Lecture, and he dubbed the method the Undrained Strength Analysis (USA). We also recommend this approach (c.f., Bromwell, 1984).

This subject was also recently discussed at Hydraulic Fill Structures '88.

5. The geotechnics of hydraulic placement of tailings is very important with regard to construction cost and dam stability.

Tailings deposition is also being studied for insights regarding the behavior and properties of natural, sedimentary soils (c.f. Imai, 1981; Schiffman et al., 1988; Carrier, 1988).

6. Non-linear, finite strain consolidation computer models have been successfully used to analyze and design tailings disposal areas.

Many finite strain computer models are now available; recent anthologies include: Yong and Townsend (1984); Montgomery and Leach (1984); and Moudgil and Somasundaran (1985). In Section 3.2.2, we discuss an important case of finite strain consolidation that does not require a computer program.

In addition, centrifuge models are being used to study consolidation of tailings and other mineral wastes (c.f., Bloomquist and Townsend, 1984; Croce et al., 1984; Lawver and Carrier, 1984; Mikasa and Takada, 1984; de Mello and Carrier, 1987). The centrifuge technique is particularly well-suited for this application, because the properties of these materials are much simpler than natural soils, due to their having been completely remolded and redeposited as a slurry.

7. Correlations between landslides and rainfall have been well established.

This continues to be a topic of great technical and economic interest. Recent conferences that included this subject were: (1) First International Conference on Geomechanics in Tropical Lateritic and Saprolitic Soils (1985); (2) Eighth Panamerican Conference on Soil Mechanics and Foundation Engineering (1987). In Section 2.1.3, we discuss the effect of the solar cycle on the frequency of rainfall.

And now, our report.

2 NATURAL VS. MAN-MADE

Prior to about 1960, the history of civil engineering, including the special field of geotechnical engineering, dealt with the impact of the natural environment on civilization. Whether it was building a canal, a railroad, a dam, or a high-rise structure, the purpose of the civil engineer was to bend nature to the will and use of society. The only concern with the environment was to be sure that the waste products of human activity were deposited far enough away so that they would not infect the people who had generated them.

An example is the Chicago River, which was made to run backwards in 1900 (c.f., Schodek, 1987). Before then, the waste from Chicago flowed into the river, and from there into Lake Michigan. Because the lake was the main source of fresh water for the City, it soon became apparent to the citizens that they were poisoning themselves: an outbreak of cholera and other diseases in 1885 caused the deaths of roughly 30,000 people, nearly 12% of the population. Thereafter, it was decided to excavate the river so that it would flow away from the lake and take the wastes to the Mississippi River and ultimately to the Gulf of Mexico. In effect, water from Lake Michigan was used to flush the river and send it elsewhere: "the solution to pollution is dilution." Reversing the flow of the Chicago River was a major engineering feat, involving a greater volume of excavation than the Panama Canal. It was intended to be a comprehensive, long-term solution. But, inevitably, as the population expanded downstream, water treatment plants had to be added, starting in the 1920s. And Chicago is presently constructing a multi-billion dollar system to control and treat stormwater and wastewater.

Starting in the US in the early 1960s, when it appeared that engineers had conquered the major natural challenges (pestilence, famine, shelter), a subtle shift in thinking began to occur. With the beginning of the "environmental movement," it became important to protect other species, and even inanimate objects, from the wastes of civilization. The purpose of the civil engineer was no longer to change the natural environment but to preserve it. For nearly thirty years, more emphasis has been given to the impact of mankind on the environment, rather than the other way around.

In this report, we will be primarily concerned with man-made impacts on the environment. But in order to establish some perspective, we will also briefly discuss the impact of the natural environment on civilization.

2.1 Impact of the natural environment on civilization

2.1.1 The Earth as a dynamic heat engine

Coincidentally, at the same time that the environmental movement was starting in the 1960s, a revolution in geology was also occurring. At first scoffed at, then dimly understood, and now fully embraced, the concept of continental drift and plate tectonics has completely altered geologic thought (c.f. Press and Siever, 1982; Siever, 1983; Nance et al., 1988). The Earth is now known to be a dynamic, cyclical heat engine. Thus, life exists in a thin biosphere, balanced between nuclear fusion within the Sun and nuclear fission within the Earth. The interaction of these two heat sources has affected the Earth's environment on a small and grand scale for 4.6 billion years. The thermal fluctuations that occur over short and long durations determine the course of evolution.

2.1.2 International Decade for Natural Hazard Reduction

On a very short time-scale, small perturbations in the heat from the Earth and Sun are responsible for what are called "natural disasters": earthquakes, tsunamis, landslides, volcanic eruptions, hurricanes, tornadoes, floods, and wildfire. Recognizing that the impact of the natural environment on mankind must still be reckoned with, the United Nations recently passed a resolution in support of the International Decade for Natural Hazard Reduction (IDNHR), to begin in 1990. The idea for the IDNHR started with the US National Research Council (Housner, et al., 1987). According to the Council's report, *Confronting Natural Disaster*, nearly 3 million lives have been lost worldwide in the last two decades as a result of natural disasters. Property damage during the same period is estimated to have been $25-100 billion.

The primary goal of the IDNHR is to mitigate the effects of disasters. Strategies include early warning systems, identification and avoidance of hazardous locations, and improved resistance to hazards. Geotechnical engineers will undoubtedly play a prominent role in this program. The ISSMFE will consider formal support for the IDNHR in Rio.

2.1.3 Solar cycle

On a slightly larger timescale, it is known that the number of sunspots varies cyclically, with a period of approximately 11 years. Many people have speculated that the sunspot cycle affects weather patterns on Earth. In Florida, for example, it has been observed that the rainfall also follows an 11-year cycle, and that the wettest years usually occur during the peak of the sunspot activity. Furthermore, the rainfall is especially intense on a 22-year cycle.

In fact, recent measurements indicate that the sun is 0.1% more luminous during the maximum sunspot activity than during the minimum (Horgan, 1988). This apparently small variation in solar energy is believed to cause changes in the average temperature at the poles as much as 6°C and to shift the position of storms in the North Atlantic by about six degrees latitude.

Obviously, it is the wet years that are the most important to geotechnical engineers: slope failures are more frequent; roads tend to break up; dikes and dams are threatened; excavation and compaction are more difficult; etc. As weather scientists unravel the effect of the solar cycle, geotechnical engineers will be greatly benefitted.

The current solar cycle will peak in 1991, coinciding with the 22-year rainfall maximum in Florida. The number of sunspots is predicted to be record-breaking.

2.1.4 Ice age

On a much larger timescale, during the last 1.8 million years, the Earth has been experiencing an Ice Age (c.f. Stanley, 1987). Prior to that time, the Earth was relatively ice-free; but since the beginning of the Pleistocene Epoch (see Figure 1), the Northern Hemisphere has undergone periodic glaciation. The cycle follows a saw-tooth pattern: the volume of ice grows steadily for about 100,000 years, followed by a rapid decline. Smaller oscillations in the ice volume occur with periods of 20,000 and 40,000 years. The cyclical nature of glaciation, with three predominant periods, is apparently related to cyclical variations in the Earth's orbit around the Sun (called Milankovitch cycles), coupled with the present delicate arrangement of the continents (Ingersoll, 1983).

The most recent major glacial advance, called the Wisconsin in North America, reached a peak about 18,000 years ago, as shown in Figure 2. The great ice sheets receded about 11,000 years ago, and civilization is presently enjoying an "inter-glacial" period. Of geotechnical significance, there are portions of the Northern Hemisphere that are still rebounding from the weight of the ice, which was up to several thousand metres thick; sea level was also 100 m lower than at present. Future generations of civil engineers will be very busy moving whole cities as the next glacial advance occurs. It will be interesting to see how today's carefully constructed hazardous waste disposal sites withstand glaciation.

Even during peak glacial activity, the average global temperature is only 2-5°C lower than normal. Perhaps in a few million years, the continents will drift into new positions and the cycle of the Ice Age will be broken -- at least for the time being.

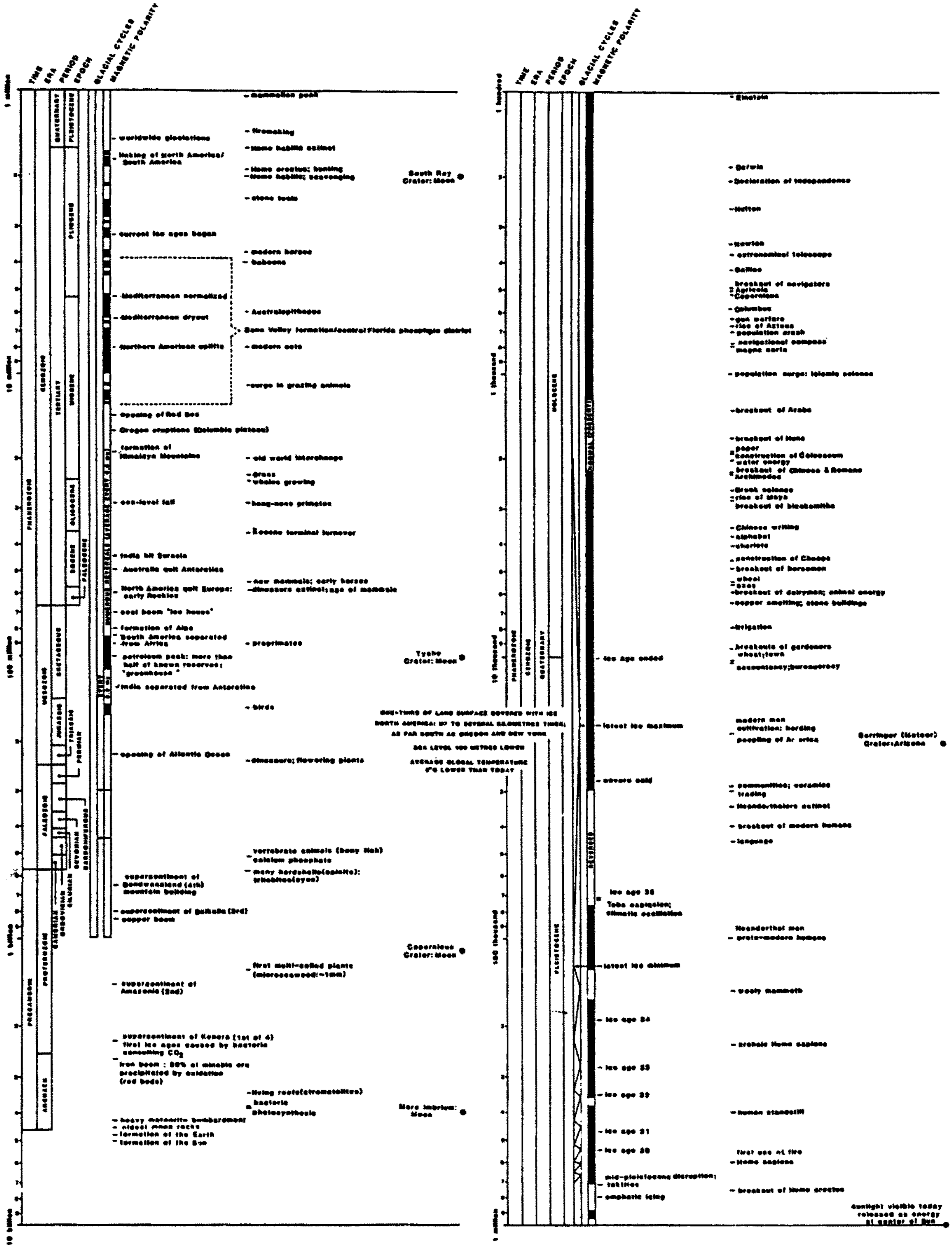


Figure 1. Geologic Time Scale (sources: Calder, 1983; Smoluchowski, 1983; Siever, 1983; Simpson, 1983; Layzer, 1984)

Figure 2. Peak Glacial Advance in Northern Hemisphere, 18,000 Years Ago (source: Stanley, 1987)

2.1.5 Extinction of species

On a much grander timescale, most of the lifeforms that ever existed on Earth are now extinct. Millions of species have died since multicellular life began over a billion years ago in the Precambrian Time (see Figure 1). For example, there have been at least 10,000 species of cephalopods that utilized an external shell for combined protection and buoyancy control: now, only five remain (Ward, 1987). These five are all very similar and are commonly referred to as the pearly, or chambered, nautilus. The nautilus is a fascinating sea creature and is even the subject of a poem by Oliver Wendell Holmes (1858).

Every so often, a mass extinction of species occurs. The most extreme extinction occurred about 250 million years ago, at the end of the Paleozoic Era. During a period of about 10 million years, roughly 75 to 90 percent of all preexisting marine species disappeared (Stanley, 1987). For the first time, terrestrial vertebrates were also severely affected.

The most famous mass extinction was the demise of the dinosaurs (and about half of the species then on Earth), which occurred about 65 million years ago at the end of the Mesozoic Era. This mass extinction is of particular interest to humans, because without it, dinosaurs likely would have continued to be the dominant lifeform on Earth, as they had been for the previous 160 million years. Mammals during the Age of Dinosaurs were small, rodent-like creatures, probably nocturnal. The disappearance of the dinosaurs cleared the way for the Age of Mammals and the evolution of our own species.

Only about a dozen major mass extinctions have been identified, and in fact, the number of species lost during these episodes is small compared to the total species that have disappeared since life began. And mass extinctions are not sudden events; they generally extend over several million years, and involve multiple pulses. New species evolve even as the old ones die. Still, mass extinctions are important because whole orders and classes of animals disappear during these episodes. Furthermore, there is some evidence that mass extinctions occur at regular intervals of 26 to 32 million years. This apparent periodicity has led some scientists to speculate that mass extinctions are caused by either meteorites or comets striking the Earth (Beardsley, 1988). Other scientists have argued that most, if not all, mass extinctions are due to climatic cooling (Stanley, 1987). The cooling, in turn, is believed to be caused by continental drift, which alters patterns of flow in the oceans and the atmosphere. Still other scientists think that the extinction of the dinosaurs, at least, was caused by intensive volcanic activity at the end of the Mesozoic Era, coupled with a lowering of sea level, which also occurred then (Beardsley, 1988).

Whatever the cause (or causes), mass extinctions will continue to occur. They represent the penultimate impact of the natural environment on civilization. The ultimate impact will occur about a billion years from now, when the Sun expands beyond the Earth's orbit. When that occurs, the entire planet will return to the superheated plasma from whence it came.

2.1.6 Radon

Finally, on the grandest timescale, radon gas has been present since the Earth was created approximately 4.6 billion years ago. Radon is colorless, tasteless, and odorless; and it is the heaviest gas known, with a density about 7.6 times that of air. Radon belongs to the group of elements known as noble gases, and is, therefore, chemically inert. There are at least 28 isotopes of radon, all of which are radioactive with relatively short half-lives. Most of these isotopes are man-made and are only found in physics laboratories; only three isotopes occur naturally from the decay of other radioactive elements. Each, in turn, decays into another element.

The natural isotope that we are concerned with has an atomic mass of 222 (Rn^{222}) and a half-life of 3.8 days. It occurs in a decay series (see Figure 3) that starts with uranium-238, which has a half-life of 4.5 billion years. The natural fission of U^{238} in the interior of the Earth contributes to the heat that drives continental drift. Uranium-238 decays to thorium-234, and so on through radon-222, culminating in lead-206, which is stable (non-radioactive). At each step of the decay process, energy and/or charged particles are released. What makes radon-222 unique is that it is the only gas in the decay series: all of the other elements are metals, and, hence, relatively immobile.

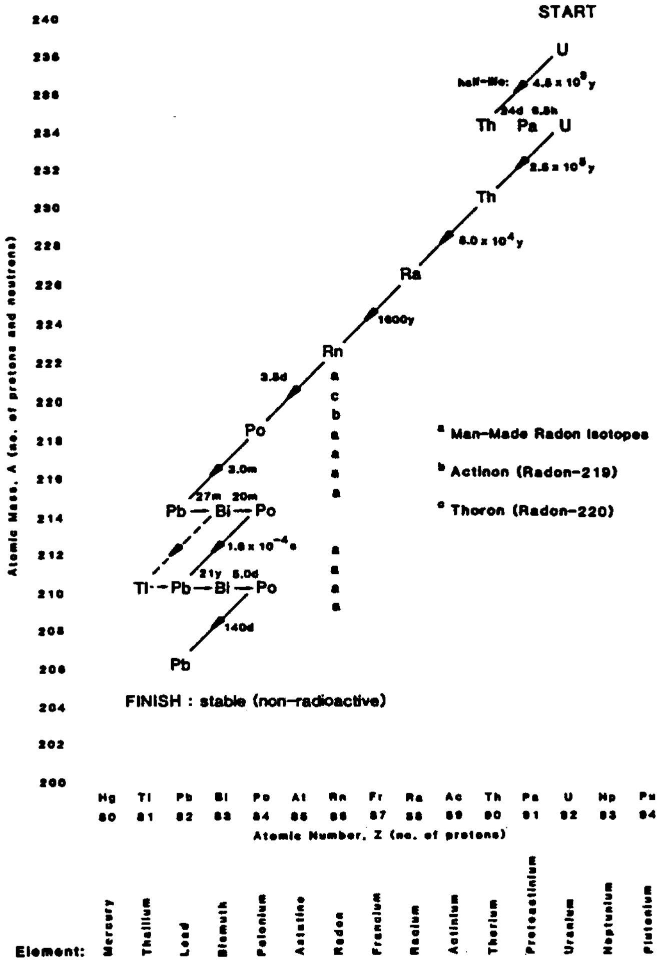


Figure 3. Natural Radioactive Decay Series of Uranium-238

As a gas, radon-222 has the opportunity to move; and with a half-life of 3.8 days, it has a chance to be inhaled into people's lungs. (The other two naturally occurring isotopes of radon, actinon (Rn^{219}) and thoron (Rn^{220}), are produced in two other decay series that start with uranium-235 and thorium-232. Their half-lives are 4.0 s and 55.6 s, respectively, and, thus are of no practical consequence: they decay into the next element before they can move very far.) Once in the lungs, radon-222 can decay into polonium-218. As a metal again, and chemically active, the radioactive particle can attach to the lining of the lungs and the rest of the decay series (lead-214, bismuth-214, etc.) can occur there. Alternatively, the decay metals can become attached to dust particles in the air and subsequently be inhaled.

The concentration of radon gas in outside air is approximately 0.1 to 0.3 picocuries per liter (pCi/l). This is a fraction of the total natural radiation that humans receive from terrestrial and cosmic sources. But the air within the pore spaces of soil typically contains 10 to 10,000 pCi/l and, and a small portion of that radon seeps into buildings: the air in the average US home has a concentration of about 1.5 pCi/l (Nero, 1986). The radiation dose received from radon by an occupant in an average US home is approximately three times that from all medical procedures. It is estimated that the average concentration of radon in US homes causes about 10,000 cases of lung cancer per year. Furthermore, about 2% of US homes have concentrations greater than 8 pCi/l. A few homes, built near uranium-bearing granite, have concentrations greater than 100 pCi/l. According to Nero (1988), "... hundreds of thousands of Americans living in houses that have high radon levels receive as large an exposure of radiation yearly as those people living in the vicinity of the Chernobyl nuclear power plant did in 1986 ..." Estimates of radon-related cancer deaths in the US range from 5,000 to 20,000 per year. However, these estimates of lung cancer rates are hotly debated. They are based on an extrapolation of mortality rates that have been observed for people who formerly worked in poorly ventilated underground uranium mines. Only a few people have demonstrably died of lung cancer due to radon.

In any case, radon has received more sustained publicity than any other natural geotechnical hazard. Radon has been of special interest in Florida, because small quantities of uranium occur within the phosphate ore that underlies large portions of the State. A few years ago, Florida became the first State in the US to write a regulation regarding exposure to natural radiation (Florida Administrative Code, 1986). The rule specifically required that the average annual radon decay product concentration not exceed 0.02 working level (WL) in new homes, schools, and commercial buildings. The guideline of 0.02 WL (radon decay product concentration) is generally taken to be equivalent to 4 pCi/l (radon concentration) but even this is subject to debate. Some people think the guideline should be much lower, perhaps at an indoor "background" of 0.005 WL or 1 pCi/l.

Because of the controversy surrounding this new exposure rule, it was not implemented. Instead, a statewide survey of more than 6000 existing homes was performed (Nagda et al., 1987). This was one of the most comprehensive studies of indoor radon pollution conducted to date. It was found that the average radon concentration in Florida homes is 0.8 pCi/l, well below the national average. The single-highest measurement was 32.4 pCi/l, which occurred in Marion County. In Polk County, where one of us lives, and which is known for phosphate mining, the average concentration is 1.4 pCi/l, still slightly below the national average. The maximum concentration measured in Polk County was 13.2 pCi/l, found in a home built on unmined land, and 11.5% of the tested homes exceeded the guideline of 4 pCi/l. Interestingly, the maximum concentration of radon in Polk County soil was 6587 pCi/l, which was the highest value measured in the State. Altogether, portions of 18 counties were found to have definite evidence of elevated radon potential, representing about 7% of the land area of Florida. Another 14 counties were found to have limited evidence of elevated radon potential; and 35 counties were found to have no evidence of elevated radon.

The Florida Department of Health and Rehabilitative Services has described three alternative construction techniques for reducing the potential for radon entry from the soil: (1) Improved monolithic slab, (2) Post-tensioned slab, and (3) Ventilated crawl space beneath the floor (Pugh, 1988). Comparison of actual construction costs has shown that these methods do not significantly increase the cost of a new home (Scott and Findlay, 1987). It is generally agreed that local building codes should require these techniques in those areas where elevated radon concentrations have been found.

A deeper policy question is: what should be done about the existing homes and buildings in high radon areas? Some people have argued that a warning should be included on property deeds, while others have argued that no action is required. A law recently enacted by the Florida State Legislature takes a middle road; it requires the following notice for the sale of any building in Florida: "Radon is a naturally occurring radioactive gas that, when it has accumulated in a building in sufficient quantities, may present health risks to persons who are exposed to it over time. Levels of radon that exceed federal and state guidelines have been found in buildings in Florida. Additional information regarding radon and radon testing may be obtained from your county public health unit." (Florida Statutes, 1988). The law also (1) Creates the Florida Coordinating Council on Radon Protection, (2) Establishes a legal process for certification of professionals to perform radon measurements and mitigation (Florida Administrative Code, 1988); and (3) Requires that new building codes be written for radon-resistant buildings by 1990; all of this to be funded by a tax of $0.01 per square foot on new construction. (It makes one wonder how our ancestors fared living in caves!)

Ventilation of a building generally lessens the hazard of radon, but ventilation can also suck more radon out of the soil and into the building. To minimize radon entry, either the gas must be vented before it reaches the underside of the building, or the underside must be made impermeable. Because radon occurs naturally everywhere, it should be important to geotechnical engineers worldwide.

2.2 Impact of civilization on the natural environment

In Section 2.1, we have briefly reviewed the natural forces and cycles which have affected and continue to affect life on Earth. By comparison, most human activity is rather puny. Important exceptions include chopping down the tropical forests or conducting nuclear war, either of which appear to be roughly equivalent to a mass extinction (c.f., Myers, 1988). Furthermore, the ability of humans to alter the natural environment is growing rapidly: there is increasing concern that human society will foul its own nest. In this portion of Section 2.0, we will discuss the philosophical, technical, and legal trends regarding the impact of civilization on the natural environment.

2.2.1 World Commission on Environment and Development

The World Commission on Environment and Development (WCED) was established in 1983 by the United Nations (Brundtland et al., 1987). In its report, Our Common Future, the WCED concluded that the global economy and the global ecology are now inextricably linked. Whereas, in the past, a nation's economy and ecology were fairly independent of any other nation's, now, with a world population of 5 billion, civilization is bumping into limits: one nation's electrical power is another nation's acid rain. According to UN projections, the world population is expected to stabilize between 8 to 14 billion during the twenty-first century. Another world of humans in less than one hundred years will greatly increase the pressure on existing resources. This is the lesson of the Chicago River writ large.

According to the WCED, what appear to be isolated disasters are, in fact, evidence of mismanagement of the global economy and ecology. The WCED cites as examples Bhopal, Chernobyl, and the deaths of 60 million people due to diarrheal diseases, all occurring during a period of less than three years (see Table 1).

TABLE 1

WORLD COMMISSION ON ENVIRONMENT AND DEVELOPMENT: MISMANAGEMENT OF GLOBAL ECONOMY AND ECOLOGY

"The WCED first met in October 1984, and published its report 900 days later, in April 1987. Over those few days:

- o The drought-triggered, environment-development crisis in Africa peaked, putting 35 million people at risk, killing perhaps a million.
- o A leak from a pesticides factory in Bhopal, India, killed more than 2,000 people and blinded and injured over 200,000 more.
- o Liquid gas tanks exploded in Mexico City, killing 1,000 and leaving thousands more homeless.
- o The Chernobyl nuclear reactor explosion sent nuclear fallout across Europe, increasing the risks of future human cancers.
- o Agricultural chemicals, solvents, and mercury flowed into the Rhine River during a warehouse fire in Switzerland, killing millions of fish and threatening drinking water in the Federal Republic of Germany and the Netherlands.
- o An estimated 60 million people died of diarrheal diseases related to unsafe drinking water and malnutrition; most of the victims were children."

-- after Brundtlant et al. (1987)

The WCED concluded that sustainable development in the next century can only be achieved if world energy is based on renewable sources. In our opinion, this is a rather static view of the future, as it neglects the profound effect of technology. For example, the US National Aeronautics and Space Administration (NASA) is currently studying the possibility of mining helium-3 on the Moon, for use in nuclear fusion reactors on Earth. It is estimated that there is enough helium-3 on the Moon to supply the world's energy requirements for nearly 2000 years (Kulcinski, et al., 1986; Sviatoslavsy and Jacobs, 1988). And there is enough helium-3 in the atmospheres of Jupiter, Saturn, Uranus, and Neptune to supply energy for billions of years. Geotechnical engineers may be helping to design a base on the Moon in the next 20 years, and a base on Europa (an ice-covered satellite of Jupiter) by the middle of the 21st century (Leonard et al., 1987). Nonetheless, the conclusion reached by the WCED is clear: this is Spaceship Earth, and we are all in it together.

2.2.2 Closed-loop life support system

In order to make long-duration manned spaceflight more efficient and less costly, NASA is studying a method of minimizing the weight of "consumables," such as food, water, and oxygen. The system is called Closed-Loop Life Support, and is illustrated in Figure 4. The intent is to recycle as much of the consumables as possible; that is, waste products would be converted back to usable materials. The technology will be based either on chemical/physical processes or plant-life, or a combination of the two. The ultimate goal is to recycle all of the materials indefinitely; only energy would be added to the system and only waste heat would be removed.

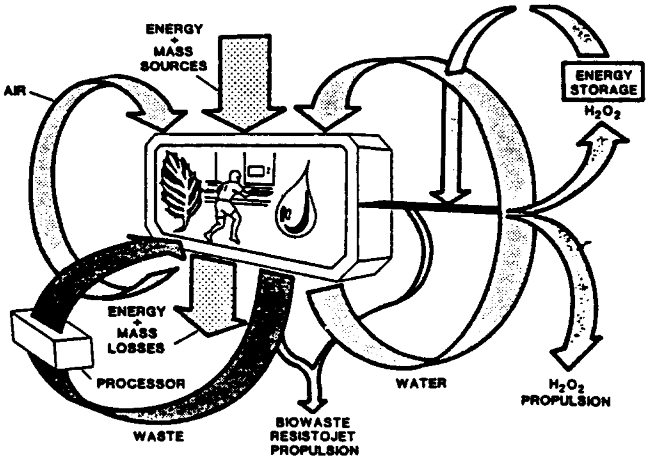


Figure 4. Elements of a Closed-Loop Life Support System (source: NASA, 1987)

The Closed-Loop Life Support system is, of course, a microcosm of the Earth. As human activity has increased, however, the Earth's natural systems for recycling waste are becoming overloaded. The goal of the next century must be to return the Earth to a Closed-Loop Life Support system. In fact, as additional energy is consumed, engineers will have to learn to "dump" waste heat into space, otherwise civilization will be overwhelmed by thermal pollution.

2.2.3 Second law of thermodynamics

The US is presently embarked on a vast clean up of hazardous waste dump sites. In many cases, the hazardous waste is being contained in situ by constructing a soil-bentonite slurry cutoff wall around the perimeter of the dump site (this method is discussed in more detail in Section 3.1.2). Some simplistic calculations suggest that the US will run out of mineable bentonite well before the thousands of dump sites are all contained. In order to complete this program, the US may have to import bentonite. Even if this does not occur, extensive mining in the US will create large areas of land that must be reclaimed. To make matters worse, the US bentonite mines are primarily located in arid regions, such as Wyoming, that are difficult to reclaim. Whether or not the US imports bentonite, a limited resource will have been depleted. Furthermore, moving large quantities of bentonite around the country will require transportation, distribution, storage, etc., and thereby will consume more resources.

This example suggests the following environmental engineering "law": any reduction in pollution at a given location increases the pollution somewhere else; and furthermore, the net pollution is increased: more pollution is created than eliminated. This is roughly equivalent to the second law of thermodynamics, which states that entropy always increases: the best that anyone can do is to reduce entropy in a local region at the expense of increasing entropy in the universe.

Our proposed environmental engineering law may not be as strictly rigorous as the second law of thermodynamics, but the point is, any solution for a particular pollution problem must meet two criteria: (1) The net increase in pollution must be minimized (ideally, it would be zero or negative); and (2) The "new" pollution must be distributed on an equitable basis. Once again, this is the lesson of the Chicago River and is one of the basic themes developed by the World Commission on Environment and Development (see Section 2.2.1). The WCED cited the following simple examples of inequitable downstream effects: "Deforestation by highland farmers causes flooding on lowland farms; factory pollution robs local fishermen of their catch."

In the past, it was sufficient for a geotechnical engineer to optimize the solution for his particular project. Now, a geotechnical project must be seen as a subsystem of a larger system and the whole system must be optimized. The big picture has gotten bigger.

2.2.4 Model geotechnical codes

One of the consequences of a global economy is that a manufacturing facility can be built wherever in the world that the benefit-cost ratio is maximized. Part of the financial equation includes the local pollution laws and regulations. Some companies seek locations with lax rules in order to reduce their cost and enhance their competitive position. Similarly, some countries are known to offer lower pollution standards in order to attract foreign investment: in effect, an ecological tax incentive.

Recognizing that the global economy and ecology are interdependent, we recommend that the ISSMFE develop model geotechnical codes for environmental protection. These model codes would not be mandatory within any legal jurisdiction. But those geotechnical engineers who desire to have the codes formally adopted within their own countries would be greatly assisted by the international stature of the ISSMFE. And, of course, the codes could also be modified as appropriate to reflect local conditions. But the goal is to raise the standard of practice and to give legal support for high quality engineering.

Developing model geotechnical codes is a new role for the ISSMFE; it would be an ongoing task and would require much effort. But someone must do it. We believe that the ISSMFE is the only logical organization.

3 AMERICAN PERSPECTIVE

3.1 Solid, liquid, and hazardous wastes

3.1.1 New facilities

In the US, there are four options presently available for disposal of solid, liquid, and hazardous wastes: (1) Burial (landfill for most solid and hazardous wastes; deep well injection for some liquids); (2) Chemical treatment; (3) Recycling; and (4) Incineration. A given substance may undergo a combination of these, as indicated in Figure 5. The generation, handling, transportation, and disposal of wastes is subject to an ever-increasing volume of local, State, and Federal regulations (see Figure 6). As of 1986, the Federal environmental regulations alone totalled 8500 pages (Hirschorn, 1988). The most important laws are: National Environmental Policy Act, Resource Conservation and Recovery Act (RCRA), Clean Air Act (CAA), Clean Water Act (CWA), Safe Drinking Water Act (SDWA), and Toxic Substances Control Act (TSCA).

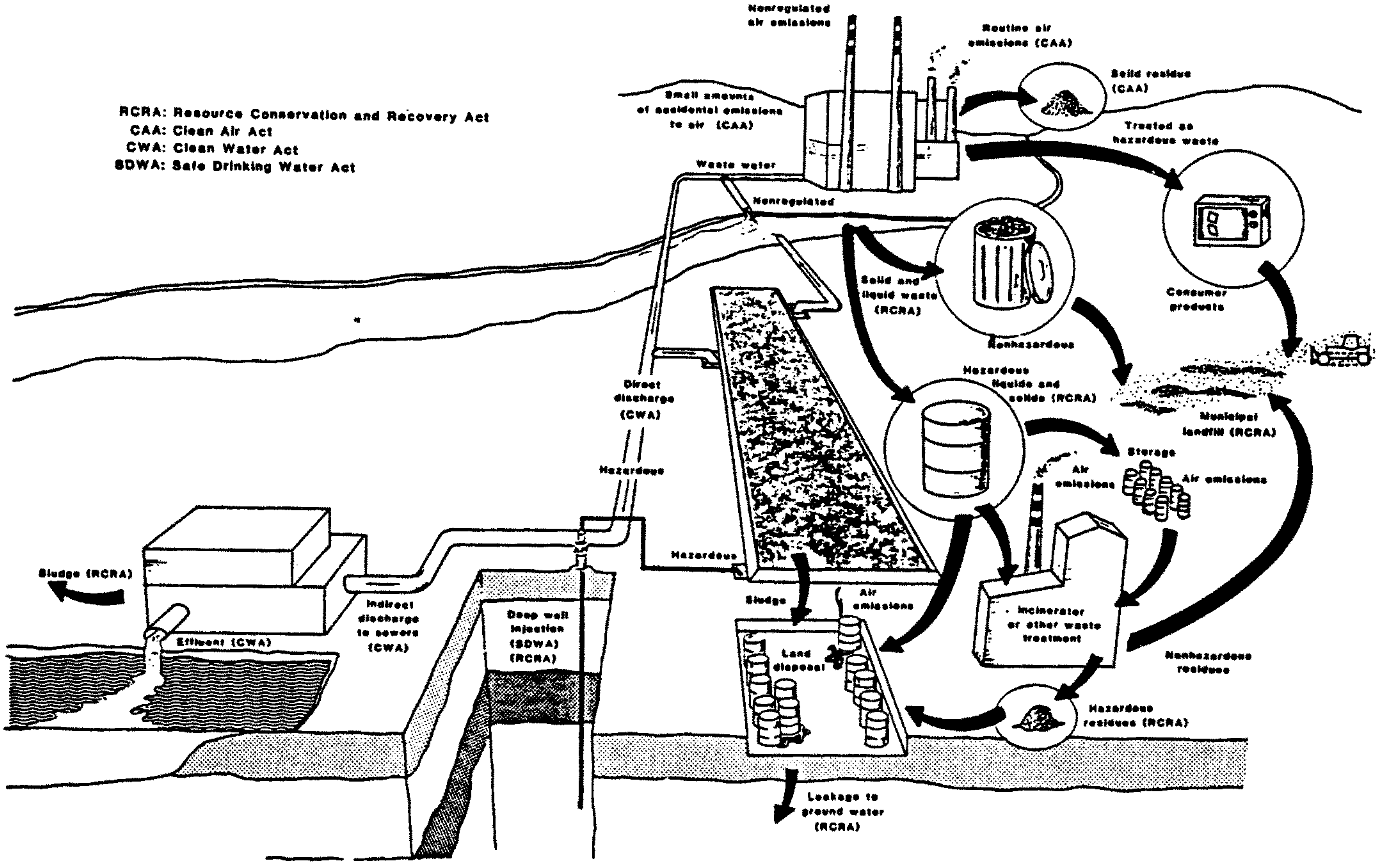


Figure 5. Regulation of Waste Disposal in the United States (source: Hirschorn, 1988)

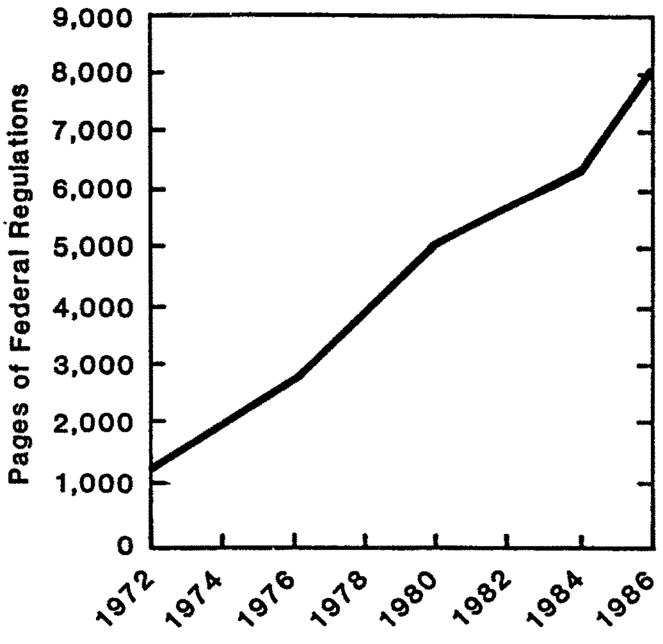


Figure 6. Growth of Federal Environmental Regulations in the United States (source: Hirschorn, 1988)

Minimum standards for design and construction of landfills are set by the US Environmental Protection Agency (USEPA) under the authority of RCRA. These standards are periodically updated; the present "state-of-the-art" (USEPA, 1985) is called a double composite liner and is shown in Figure 7. (c.f., Buranek, 1987; Cope, 1987; Duplancic et al., 1987; Kelly and Bogardi, 1987; Koerner and Richardson, 1987; Schubert, 1987; Vardy, 1987). The double composite liner system includes two geomembranes, two compacted clay layers, and two leachate collection zones. The USEPA requires that the leachate leaking through the top liner be monitored daily and be limited to 0.047 to 0.19 m^3/ha/day (USEPA, 1987).

Each State in the US may regulate its own landfills, provided that it adopts a program that meets the minimum USEPA criteria. For example, the New York State Department of Environmental Conservation recently announced proposed landfill regulations that are intended to be the strictest in the US (ENR, 1988e,f). The new regulations would require a double composite liner and leachate collection system with an estimated construction cost of roughly $US 1 million/hectare, excluding the leachate piping.

Some legal authorities in the US have suggested that the design of a landfill has become codified to such an extent that strict liability will apply. In other words, a geotechnical engineer would be liable for any repairs or damage associated with the landfill, just as a manufacturer is required to warranty its products. On other types of projects, the geotechnical engineer is not liable provided he has practiced in accordance with a "reasonable standard of care"; i.e., average quality as compared to other geotechnical engineers. Whereas, for a landfill, the geotechnical engineer may have to warranty his product for as long as 30 years. This potential financial liability may effectively remove the geotechnical engineer from this market.

The US produces about 136 million tonnes of municipal solid waste annually, or more than 1.5 kilograms per person per day. Landfill disposal facilities are filling up rapidly: there were 500 permitted sites in Florida in 1979; nine years later, there were just 170 (Lawhorne, 1988). Nationwide, nearly one-third of the existing landfills are expected to be at capacity in the next 5 to 7 years (Hoffmann, 1988). In some areas, the disposal cost exceeds $90/tonne, compared to less than $10/tonne a few years ago.

In addition, the Office of Technology Assessment of the US Congress concluded in 1985 that burial of hazardous wastes is not a long-term solution. Consequently, the USEPA was authorized in 1986 to support research on alternative or innovative treatment technologies (USEPA, 1988). These presently include thermal, chemical, biological, and electrical techniques, as summarized in Table 2.

As a result of these trends, recycling has been gaining in popularity. In Florida, for example, the Department of Environmental Regulation recently announced plans to raise the proportion of recycled municipal waste from 10% to 33%. Furthermore, non-recyclable materials are being reduced: fast food restaurants will not be permitted to use polyvinyl and polystyrene foam containers in Florida after mid-1990. Manufacturers are also finding that reduction of hazardous wastes is often less expensive and risky than disposal (Piasecki and Davis, 1987; Hirschorn, 1988; Dolin, 1988). Reduction is achieved either by

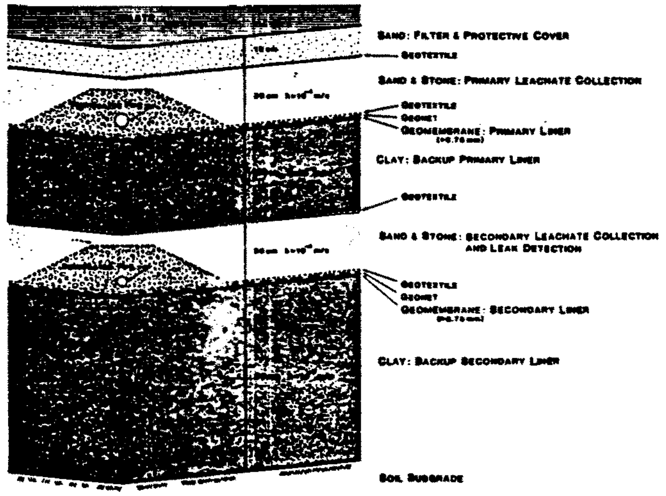


Figure 7. Current "State-of-the-Art" Double Composite Liner System for Hazardous Waste Landfills in the United States

TABLE 2

NEW TREATMENT TECHNOLOGIES FOR HAZARDOUS WASTES

(a) ABOVE GROUND - EXCAVATION

<u>Thermal</u>	
1. Circulating bed combustor	Improvement over traditional fluidized bed combustion (greater turbulence)
2. Infrared	Electrically-powered silicon carbide rods; up to 1000°C; afterburner required for remaining combustibles
3. Electric Pyrolysis	Thermal destruction without combustion: disassociation of organic molecules into individual atoms; up to 1800°C
4. Oxygen-air-fuel burner	Fitted onto any conventional combustion unit; up to 2500°C; more complete incineration
5. Pyroplasma	Electric plasma torch destroys liquid organic waste by disassociation; 5000° to 15,000°C
6. Centrifugal reactor	Plasma heat decomposes organics
<u>Chemical</u>	
1. Solidification/Stabilization	Patented nontoxic chemical blend encapsulates organic molecules for solidification; then mixed with pozzolans (fly ash, kiln dust, cement) and water for stabilization.
2. Solvent extraction	Liquified gases act as solvents to remove organics from sludge, solid or liquid wastes
3. Fixation/Stabilization	Soluble silicates and silicate setting agents
4. Volume reduction/ Solidification	Mixed with asphalt; extruder-evaporater unit; organic volatiles treated with caustic solution and ozonation
5. Solidification/Stabilization	Microblending and microencapsulating with patented reagent; pozzolanic reaction to stabilize
<u>Biological</u>	
1. Microbial Digestion	Accelerated growth of proprietary naturally occurring nonpathogenic organisms: final products are CO_2, H_2O and cell protoplasm (new food source)
2. Biological reactor	Fixed-film, activated carbon fluidized-bed biological reactor; uses pure O_2
3. Powdered Activated Carbon	PAC added to aeration basin
4. Liquid/Solids Contact Digestion	Three stages: water and emulsifiers; acclimated seed bacteria; biological step to achieve target concentrations

(b) ABOVE GROUND - EXTRACTION

1. Volatile extraction	Extraction well and vacuum pump; air emission control equipment
2. Ion exchange	Removal of heavy metal ions from groundwater

(c) <u>IN SITU</u>

<u>Thermal</u>	
1. Vitrification	Electrodes inserted into soil; hood over ground surface to collect and treat gases
2. Radio waves	Electrodes; removal of volatile organic compounds; hood for collection
<u>Chemical</u>	
1. Soil mixing	Proprietary chemicals mixed with hollow drill/blade system; soil columns stabilized and solidified ground surface covered with asphalt
<u>Biological</u>	
1. Microbial Digestion	Accelerated growth of proprietary naturally occurring nonpathogenic organisms: final products are CO_2, H_2O and cell protoplasm (new food source); only practical for shallow deposits
<u>Electrical</u>	
1. Electro-Kinetic	Electrodes inserted into soil; removal of heavy metal cations

recycling materials within a manufacturing plant, or by devising a new processing technology that does not produce hazardous waste in the first place.

Incineration is also a rapidly growing market, often in combination with recycling (Kosowutz, 1988a,b; O'Leary et al., 1988; ENR, 1988g). In the typical US household, about 7% of the wastes are plastic containers and wrapping for food, clothing, and other consumer products. The waste is usually placed in a 20 to 40-litre plastic container that is lined with a plastic bag, often located in the kitchen. Usually once a day, the plastic bag is closed and placed in a larger plastic container that is also lined with a plastic bag. Then, once or twice a week, the large plastic bag is collected and transported along with thousands of other plastic bags to a landfill that is lined with -- plastic.

For many years, incineration of municipal waste has been common in Europe; but it was said that incineration was not practical in the US, because burning plastic released acid gas pollution. (This is a little reminiscent of the old vaudeville gag that goes like this: A man goes to a doctor. He says, "Doctor, it hurts when I do this." And the doctor says, "Well, don't do that!") Because of improvements in air pollution technology, refuse-to-energy plants are now growing in popularity in the US. A new plant in California is reported to achieve 99% removal of acid gas (Salimando, 1988). Florida currently leads the US in refuse-to-energy projects (Jones, 1988), including the world's largest plant (ENR, 1988d), but a policy question remains concerning the classification of the ash: some people consider the ash to be merely solid waste while others believe it to be hazardous waste. The solution will probably be to dispose of the ash in dedicated landfills, or to stabilize it chemically.

Incineration of hazardous waste has recently increased dramatically. This is the result of RCRA, which banned bulk or containerized liquids from hazardous waste landfills in 1985. As a result, more than 1 million cubic metres of liquid wastes are now burned annually in cement kilns, light aggregate kilns, and industrial boilers (Schofield and Vingris, 1988; ENR, 1988b). A huge market for RCRA-permitted hazardous waste incinerators is projected in the near future (Civil Engineering, 1988).

Recycling and incineration of municipal and hazardous wastes require geotechnical engineering only for the foundation design of the plant, similar to any other industrial facility. However, we estimate that thousands of these plants will be built in the US in the next two decades.

3.1.2 Closure of old facilities

The USEPA has identified approximately 19,000 hazardous waste sites under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (Repa, 1988). CERCLA requires that a landowner pay for cleanup or closure of a hazardous waste site. When a financially responsible entity cannot be identified, the Federal government pays for the cleanup from the "Superfund," administered by USEPA. Superfund was created by imposing a tax on chemical and petroleum producers.

When property is sold, the responsibility for cleanup goes to the new owner, even if the presence of the hazardous waste is unknown. As a result, a new geotechnical service has recently arisen, that of the hazardous waste audit. For many land buyers, this has become more important than a foundation investigation, because the financial liability can be enormous if a hazardous waste site is found.

The market for hazardous waste remediation is also shifting from the public sector to the private sector (ENR, 1988c). Large industrial corporations, with multiple waste sites, are expected to contract for nearly 80% of new remediation work by 1990.

There are three options presently available for closure of an old facility: (1) Containment; (2) In situ treatment; and (3) Excavation or extraction.

Containment generally requires the construction of a vertical barrier within the soil surrounding the site. Some of these barriers include: soil-bentonite slurry cutoff wall (most common in the US); cement-bentonite slurry cutoff wall; plastic concrete cutoff wall; composite slurry wall; soil mix wall; pressure grouting; jet grouting; and vibrated beam-wall (Bergstrom et al., 1987; Evans et al., 1987; Ryan, 1987). The use of bentonite in the containment wall is very common because of its special expansive properties and low permeability. Certain pollutants can affect the physical properties of the bentonite, and other clays, and these have been and continue to be studied in detail (c.f., Acar and D'Hollosy, 1987; Brunelle et al., 1987; Daniel, 1987; Dematracopoulos and Dharmapal, 1987; Ho and Pufahl, 1987; Mitchell and Madsen, 1987; Quigley et al., 1987; Rowe, 1987; Ryan, 1987; Schubert, 1987; Yong and Samani, 1987). Research is also being conducted regarding treatment of clay with ammonium cations in order to increase its sorptive capability for non-ionic organic contaminants, such as benzene (Boyd et al., 1988; Marbach, 1988). A cutoff wall often requires a leachate collection system and is not, under these conditions, a "permanent" solution; the facility must be monitored and maintained indefinitely (see Figure 8).

In situ treatment is a recent development and much progress is being made. Existing and developing technologies include: chemical injection and stabilization, radio frequency in situ decontamination, in situ vitrification, electro-kinetic treatment, and biological degradation with naturally occurring nonpathogenic organisms (Banerjee, 1986; Blacklock, 1987; USEPA, 1988; ENR, 1988e; Bluestone, 1988; Dev and Downey, 1988).

Finally, the hazardous waste can be excavated if it is solid or extracted if it is liquid.

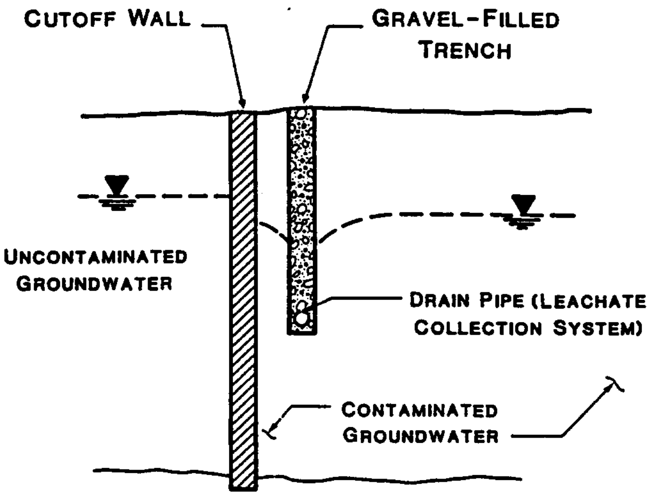


Figure 8. Cutoff Wall With a Leachate Collection System

The options available then are the same as with a new facility, as described in Section 3.1.1. Often, the newly excavated material is placed in a permitted landfill. But the accumulated volume of waste is enormous and we believe that this is prolonging the inevitable, because when the design life of the permitted landfill is reached, future generations will have to excavate the hazardous waste all over again. This is another version of the lesson of the Chicago River (see Section 2.0).

The most likely long-term solution appears to be incineration, either on-site, or at fixed facilities. (c.f., ENR, 1987; Brunner, 1988). The USEPA (1988) is sponsoring research on new technologies for incineration, including: circulating bed combustor; infrared radiant heat (up to 1000°C); electric pyrolysis (up to 1800°C); oxygen-air-fuel burner (up to 2500°C); pyroplasma (5000° to 15,000°C); and centrifugal reactor with plasma heat.

A major difficulty with incineration is estimating the quantity of hazardous material to be excavated and incinerated. The site investigation may include the best available technology in geotechnical engineering and the incineration may include the best available technology in chemical and mechanical engineering. But ultimately, the job is actually done by the lowest-paid people in the contractor's organization and they are inspected by the lowest-paid people in the engineer's organization. We are familiar with an on-site hazardous waste incineration project in the US that has received awards for its design. But the construction specifications were so poorly worded, and the project personnel so inexperienced, that all of the parties are now suing each other. Furthermore, there is evidence that not all of the hazardous waste was removed. Pay quantities have historically caused problems in construction contracts; with something as important as excavation of hazardous waste, geotechnical engineers must be especially careful in preparing the construction specifications.

3.2 Mining wastes

3.2.1 Disposal and reclamation

Technical and regulatory interest in the disposal and reclamation of mining wastes has waned in recent years. For example, the ASCE conference on Geotechnical Practice for Disposal of Solid Waste Materials, held at the University of Michigan in Ann Arbor in 1977, strongly emphasized mining wastes. A decade later, a similar conference at the same venue (Geotechnical Practice for Waste Disposal '87) barely mentioned the topic. Most of the participants at the latter conference were primarily interested in hazardous wastes and double composite liners (see Section 3.1.1). Similarly, whereas major conferences on tailings disposal occurred in the past (c.f. Aplin and Argall, 1972; Argall, 1978), nothing quite like them has happened since. The nearest equivalent is the annual Symposium on Surface Mining, Hydrology, Sedimentology and Reclamation. Finally, the publication of books on the subject has declined (c.f., Vick, 1983).

Two factors have been responsible for this. First, mining in the US has been decreasing as a result of strong international competition. Furthermore, the consumption of metals, as a percentage of per capita gross national product, has peaked in all industrialized nations and is declining. Technology is producing substitute materials, such as glass fiber for telecommunication instead of copper wire. Second, the passage of the Federal Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87) has forced the closure of small, marginal mines, which were among the worst offenders. The remaining mines, with larger financial resources, are generally able to meet stringent standards that require the land to be returned to its pre-mining condition. Most of the current technical issues involve agronomy and biology, not soil mechanics.

Mining wastes that we expect to be of more concern in the future, are: phosphogypsum, alumina red mud, oil sand sludge, potash tailings, and heap leaching facilities for gold and copper.

3.2.2 Underdrain

As mentioned in Section 1.0, a large number of non-linear, finite strain consolidation computer models have been written in the last decade. These numerical models are very useful for evaluating the filling capacity of a slurried mineral waste pond (c.f., Carrier et al., 1983).

An important class of analyses deals with the "ultimate" conditions in the disposal pond. This is defined as the maximum self-weight, primary consolidation, in which the excess pore pressure is completely dissipated. This situation normally occurs (or almost does) just before reclamation of the disposal pond is begun. Three special cases are usually considered: (1) Hydrostatic, fully submerged (water above the mudline); (2) Fully drained (water table at the base of the deposit; material still fully saturated); (3) Steady-state seepage (drainage layer at the base of the deposit; water at the mudline). All three of these cases can be evaluated by hand calculations without recourse to a computer, and the analyses are based on fundamental principles of soil mechanics.

The third case, that of steady-state seepage, is of particular interest because some members of the mining community, notably a number of alumina refineries, are spending large sums of money on bottom drains in order to increase the capacity of the disposal ponds. Hence, we have analyzed this case in some detail, as follows.

First, consider a column of slurried mineral waste, or clay, in which vertical downward seepage is occurring (see Figure 9). The upper water level is assumed to remain at the mudline; hence, the average seepage gradient is equal to 1. This seepage gradient imposes an additional increment of effective stress on the clay, which causes additional consolidation beyond what would occur under hydrostatic conditions.

For numerical analysis, the column of clay is divided into a series of layers, which for simplicity are of equal thickness, Δh_i. The initial vertical effective stress at the bottom of the top layer, $\bar{\sigma}_{i2}$, is equal to the initial buoyant unit weight of the clay, γ_b, multiplied by the initial thickness of the layer, Δh_i, plus the seepage component of stress, which is equal to the initial gradient, i_i, times the unit weight of water, γ_w, times the initial thickness of the layer:

$$\bar{\sigma}_{i2} = \gamma_b \Delta h_i + i_i \gamma_w \Delta h_i \qquad (1)$$

where i_i = initial average gradient = 1

The stress on the top of the second layer causes that layer to consolidate to a lower void ratio, given by:

$$e_f = f(\bar{\sigma}) \qquad (2)$$

where $f(\bar{\sigma})$ is a function defining the compressibility of the clay. A typical relationship for soft clays is the power function:

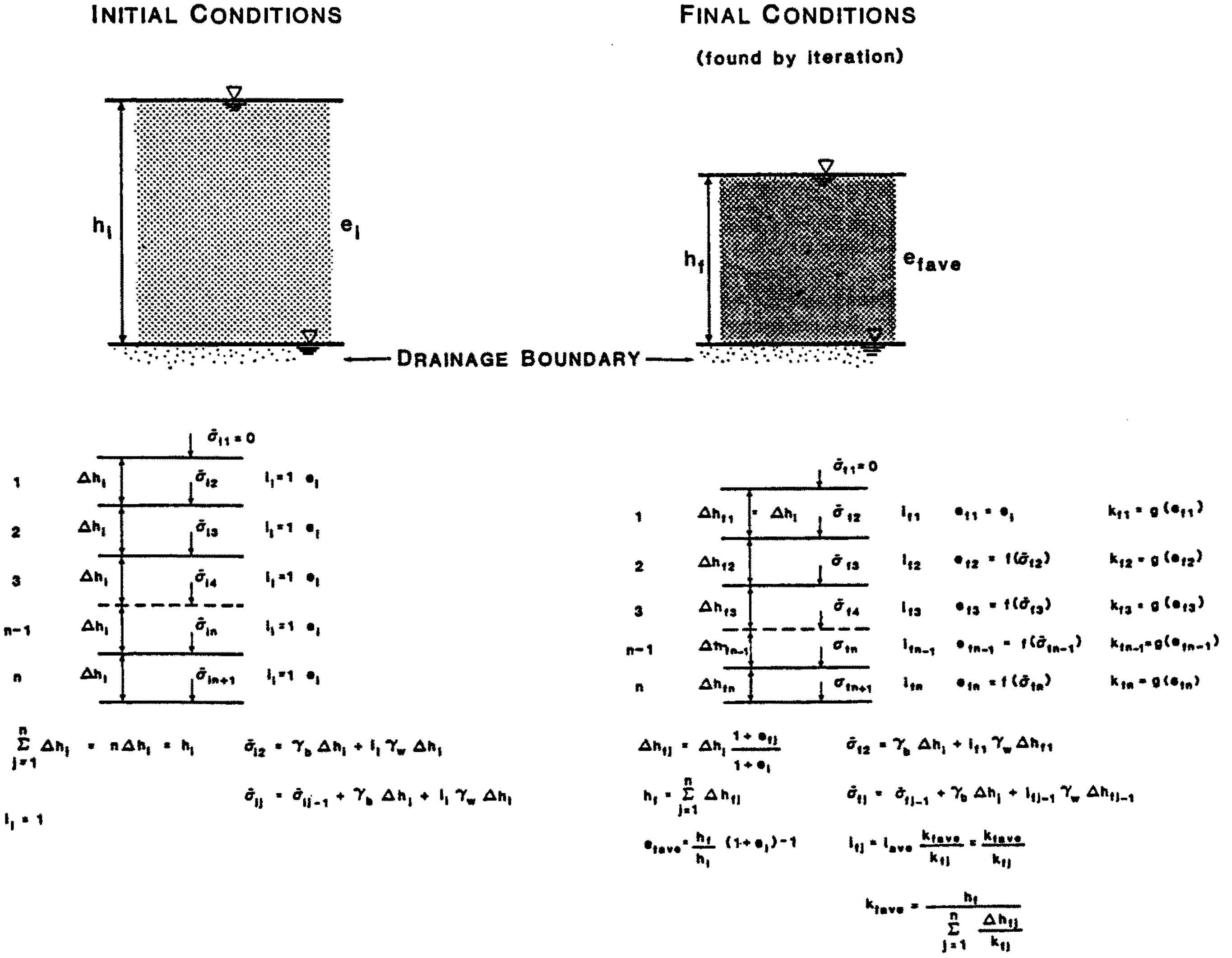


Figure 9. Ultimate Seepage-Induced Consolidation of Clay Slurry

$$e = A\bar{\sigma}^B \tag{3}$$

where A, B = compressibility parameters, measurable in the laboratory or the field

Thus, the final void ratio, e_{f2}, in the second layer is given by:

$$e_{f2} = A\bar{\sigma}_{f2}^B \tag{4}$$

The effective stress at the bottom of each successive layer is then equal to the effective stress imposed on the top of the layer, plus the increment of stress due to the buoyant weight of that layer, plus the increment due to seepage:

$$\bar{\sigma}_{fj} = \bar{\sigma}_{fj-1} + \gamma_b \Delta h_i + i_{fj-1} \gamma_w \Delta h_{fj-1} \tag{5}$$

Note that both the final layer thickness, Δh_{fj}, and the final gradient, i_{fj}, change from their initial values. The final layer thickness is obtained from the final void ratio:

$$\Delta h_{fj} = \Delta h_i \frac{1 + e_{fj}}{1 + e_i} \tag{6}$$

With Equation (6), it can be shown that the buoyant term for each layer, $\gamma_b \Delta h_i$, does not vary because the solid material remains constant:

$$\gamma_b \Delta h_i = \frac{G - 1}{1 + e_i} \gamma_w \Delta h_i \tag{7}$$

where G = specific gravity

$$\text{and } \gamma_{bfj} \Delta h_{fj} = \frac{G - 1}{1 + e_{fj}} \gamma_w \Delta h_i \frac{1 + e_{fj}}{1 + e_i} \tag{8}$$

$$= \frac{G - 1}{1 + e_i} \gamma_w \Delta h_i$$

$$= \gamma_b \Delta h_i$$

The final gradient in each layer is found by noting that the unit flow through each layer, q, is constant (continuity):

$$q = k_{fave} i_{ave} = k_{fj} i_{fj} \tag{9}$$

where k_{fave} = final average permeability of the entire column

i_{ave} = final average gradient in the entire column
= i_i = 1

$$\text{thus, } i_{fj} = i_{ave} \frac{k_{fave}}{k_{fj}} = \frac{k_{fave}}{k_{fj}} \tag{10}$$

Furthermore, the final average permeability of the column is:

$$k_{fave} = \frac{h_f}{\sum_{j=1}^{n} \frac{\Delta h_{fj}}{k_{fj}}} \quad \text{(series flow)} \tag{11}$$

The permeability is in turn a function of the void ratio of the clay:

$$k_f = g(e_f) \tag{12}$$

For soft clays, another typical power function is:

$$k = Ce^D \tag{13}$$

where C,D = permeability parameters

Thus, the final permeability, k_{f2}, in the second layer is given by:

$$k_{f2} = Ce_{f2}^D \tag{14}$$

and for each layer

$$k_{fj} = Ce_{fj}^D \tag{15}$$

Since the final gradient distribution is not known in advance, the solution for the final void ratio must be obtained iteratively. Fortunately, numerical convergence occurs rapidly and only four or five passes are required. A closed-form solution for this case has been developed by Huerta et al. (1988), which can be used to determine the compressibility and permeability parameters of soft slurries in laboratory seepage tests; however, a computer program is required to perform the calculations.

Having established the governing equations, we now turn to three numerical examples. First, consider the trivial case in which the material is essentially incompressible, such as a dense sand. The compressibility parameter, B, in Equation (3) is approximately zero and no self-weight or seepage-induced consolidation occurs. As shown in Figure 10, the gradient is constant and the pore pressure is equal to zero throughout the column.

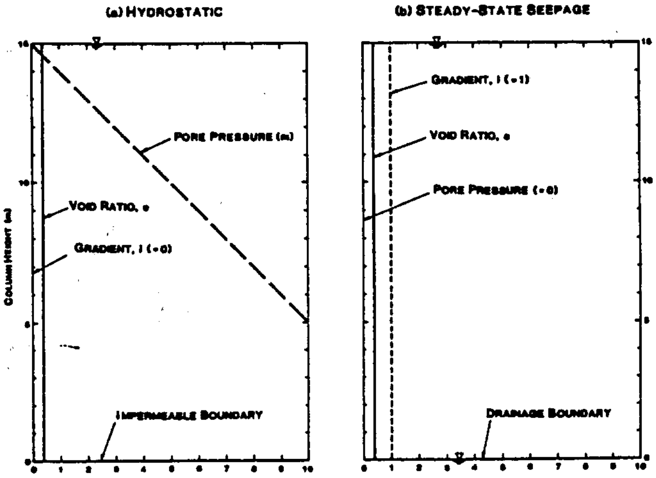


Figure 10. Ultimate Consolidation of Incompressible Material, Such As Dense Sand

Second, consider a very soft material, such as phosphatic clay. Typical compressibility and permeability parameters are: A = 35 ($\bar{\sigma}$ in Pa); B = -0.22; C = 2.9 x 10^{-12} m/s; D = 4.6. As shown in Figure 11, under self-weight hydrostatic conditions, the clay column is 15 metres high. Under steady-stage seepage conditions, the column height decreases to 13.5 m, or a volume reduction of 10%. Because of the high compressibility/low permeability of this clay, a "cake" forms at the drainage boundary. As a result, the gradient is nearly zero at the top of the column and increases to 3.5 at the bottom; and the pore pressure is nearly hydrostatic in the top half of the column and then drops off rapidly as the bottom drain is approached. Hence, with a very soft phosphatic clay, the effect of the seepage is nearly lost in the upper portion of the column, due to the formation of the cake on the bottom.

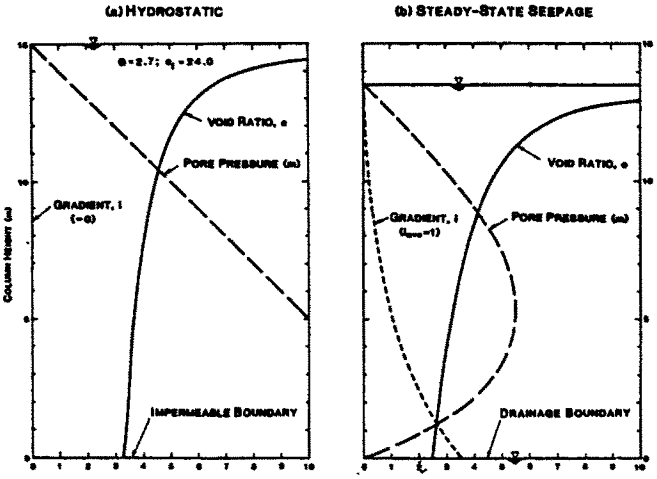


Figure 11. Ultimate Consolidation of Very Soft Material, Such As Phosphatic Clay

Third, consider an intermediate soft material, such as alumina "red mud." Typical compressibility and permeability parameters are: A = 6.9 (Pa); B = -0.1; C = 8.8 x 10^{-9} m/s; D = 3.0. As shown in Figure 12, the column height decreases to 14.2 m, or a volume reduction of 5%. A cake is not formed on the bottom, because of the lower compressibility; but the distribution of pore pressure is bowed slightly, because the permeability (and void ratio) decreases with depth.

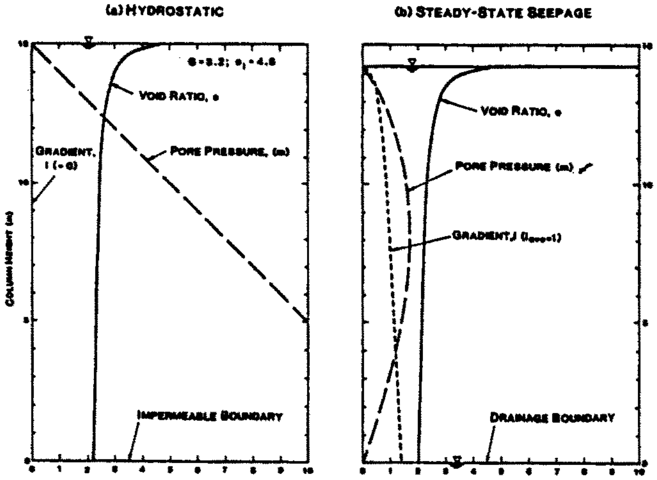


Figure 12. Ultimate Consolidation of Intermediate Soft Material, Such As Alumina Red Mud

The addition of a bottom drainage system in a red mud pond adds approximately 25% to the capital cost, but, as shown, increases the capacity only about 5%. This does not appear to be a reasonable return on investment.

4 BRASILIAN PERSPECTIVE

4.1 Introduction

The land surface of Latin America covers approximately 21 million sq km and that of Brasil approximately 8.5 million sq km. Within this immense land mass, hot and humid jungles, high mountains, grasslands, and extremely dry areas can be found.

Major engineering enterprises are being undertaken, including some of the largest embankment dams in the world, development of enormous mines and processing facilities, construction of roads in forested virgin land, nuclear power plants, ports, base industries, etc.

Geotechnical activities have dealt with all types of challenges; optimization and innovation in engineering is constantly demanded by a developing society with a high population growth rate, which has pressed the authorities to develop specific legislation to fulfill the aims and concerns of the people.

4.2 Development of regulations

Environmental impact has been locally defined as any alteration of the physical, chemical, and biological properties of the environment, caused by any matter or energy resulting from human activity which, directly or indirectly, affect: (1) Health, safety and the well-being of the population; (2) Social and economical activities; (3) The biota; (4) The aesthetical and sanitary conditions of the environment; and (5) The quality of the environmental resources.

Current environmental law requires the preparation of an Environmental Assessment Impact Report (RIMA) prior to the approval of the undertaking. The contents of the RIMA are established by the National Council of Environment (CONAMA) and complemented by State legislation. The environmental impact studies have to:

Analyze all technological and location alternatives to the project, including the hypothesis of terminating the project;

Systematically identify and assess the environmental impacts generated by all steps of construction and operation of the activity;

Define the limits of the geographic area directly or indirectly affected by the potential impact, always including the hydrographic basin in which it is located;

Consider all governmental plans and programs, proposed and being introduced in the area of influence of the project, and their compatibility.

In meeting the needs of the environmental impact assessment, the analyses have to consider, at least, the following technical topics:

1. Environmental diagnosis of the area of influence of the project, with a complete description and analysis of the environmental resources and their interaction, in order to characterize the environmental situation of the area, before the start of any work, considering:

   a. The physical habitat: subsoil, water, air and climate, emphasizing the mineral resources, the topography, the types and suitability of the soil, the water bodies, the hydrological regime, the marine and atmospheric streams;

   b. The biological habitat and the natural ecosystems: the flora and fauna, emphasizing those species that can be seen as indicators of the environmental quality, those species of scientific and economical value, those considered to be rare and threatened with extinction, and areas of proposed permanent preservation;

   c. The social-economical habitat: the use and occupation of the soil and of the water, emphasizing historical, cultural and archeological sites of the communities, the interdependence between the local society, the environmental resources and the potential future use of these resources.

2. The analysis of the environmental impact of the project and of its alternatives, through the identification, prediction of magnitude and interpretation of the importance of the probable relevant impacts, and discriminating: the positive and negative, direct and indirect, immediate and long-term, temporary and permanent characteristics of all pertinent decisions; its degree of reversibility; its cumulative and synergistic properties; the social costs and benefits;

3. Identification of mitigation measures for the negative impacts, including control equipment and systems to treat all wastes, with an assessment of their efficiency;

4. Proposal of a monitoring program of all negative and positive impacts, indicating the factors and parameters to be considered.

The report that summarizes these studies (called RIMA) is in the public domain and usually includes many charts, maps, graphs and other techniques in order to make it accessible to all interested persons.

The Brasilian Constitution, which was rewritten in 1988, establishes, in relation to the environment and among other topics, that it is mandatory to reclaim all environments degraded by mining activities. The law also establishes that any citizen has the right to demand action of the authorities, supplying information and indicating the elements of conviction. The legislation that supports all the resolutions in relation to the environment has been in effect since 1973, regulating the studies to be prepared and establishing the acceptance levels of pollutants present in the air, water and soil. A major step was taken when the CONAMA, in January 1986, defined environmental impact and established the characteristics of the studies and analyses to be made.

One of the motivating forces for consciousness and action towards environmental protection is the internal rules in international financing organizations, such as the World Bank. For approximately the last ten years, conditions attached to some World Bank loans require environmental impact assessment, protection, and reclamation.

When applied to the mining industry, the environmental legislation is enforced by the National Department of Mineral Production (DNPM). This department has, since 1970, helped to create a program of environmental control.

The experience gained in these years of work has materialized in a basic document that is in the process of being transformed into legislation. Many States in Brasil have institutions that control environmental legislation and fix levels of acceptance for pollutants (CETESB, FATMA, FEEMA, COPAM, etc.), continuously monitoring air, soil, and water quality, as well as many other variables in cities, in the coastline, and in the countryside. These institutions are also responsible for research directly and indirectly related to their area of work and have the power to police the obedience to the legislation.

4.3 Practice: a cross section of the industry

As previously mentioned, the environmental impact assessment is required in any major engineering undertaking; among the areas of interest to geotechnical engineering, the mining industry has been facing enormous challenges and has been able to produce elegant and efficient solutions and thus will be emphasized in this paper.

The mineral resources of Brasil are abundant and diverse. Iron is probably the most abundant, but bauxite, cassiterite (tin), gold, copper, nitrates, coal, niobium, and many other ores are also found. Stripped overburden and tailings are generated in many of the extraction and beneficiation facilities. An inventory of tailings production and impoundments, as well as stripped overburden, is not available, but the magnitude is enormous.

Table 3 illustrates the dimension of mining in Brasil, summarizing the production of some mineral ores in 1988, with an indication of the relative change since 1986 and 1987. Most of this mining activity is of recent origin and, as with mining, impounded tailings are also of recent origin. The proper disposal of removed overburden material is also a topic to which the industry only focused its attention in recent years. Brasil probably has some of the best examples of tailings dam design and construction, side-by-side with situations that developed during a large time span, previous to conscious engineering help and which can develop into misbehavior.

TABLE 3

BRASILIAN PRODUCTION
OF MINERAL ORES

ORE	1988 PRODUCTION (tonnes)	88/87	87/86
Bauxite	7,300,000	+ 9.0 %	+ 2.4 %
Coal	7,300,000	+ 15.9 %	-14.9 %
Cassiterite	27,000	0 %	+ 3.7 %
Iron	145,000,000	+ 6.6 %	+ 5.4 %
Manganese	2,800,000	+ 12.0 %	0 %
Nickel	14,500	+ 3.6 %	+ 3.7 %
Gold	70	+100.0 %	+45.1 %
Zinc	150,100	+ 16.6 %	+ 3.9 %

-- after Minerios: Extracao
e Processamento (1988)

Some case histories will be presented to illustrate the state-of-the-art in tailings disposal, as well as to allow some lessons to be learned from failures. These case histories do not pretend to cover the available records; a representative publication of some of the most common procedures has been chosen.

4.3.1 Disposal of solid and liquid wastes generated by the industrial processing of uranium ore

Brasil mines and processes uranium in the State of Minas Gerais. This activity generates wastes that require specific and judicious studies for their disposal (Sadowski et al., 1986). The water seeping from these wastes, as well as the flow through the spillway of the dam, requires a suitable chemical treatment to reduce its radioactivity to the limits accepted by the controlling entities. This condition imposed a demand for a strict study of the groundwater regime and geotechnical behavior of the impoundment area. Special attention was placed on seepage through the embankment and its foundations, as well as through the natural boundaries of the reservoir. Stability and risk analyses against natural hazards such as earthquakes, floods, etc., were also taken into consideration.

The location of the conventional dam that would contain the tailings included analyses of the following basic requisites: (1) Favorable characteristics of the subsoil profile of the site, both with respect to its deformability and to its seepage characteristics; and (2) Possibility of collecting all seepage in well-defined areas and re-directing the water to treatment facilities, after which the concentration of radionuclides should be lower than 10 pCi/l.

Extensive geological, geohydrological, and geomorphological studies were developed for the area of the reservoir, dam foundation, and low topographic saddles, concluding with the approval of the final site. The embankment built to contain the wastes had its foundations extensively grouted, both in the saprolite (using for the first time tubes a manchete in this procedure of treatment) and the sound rock, and its cross section optimized using stripping material from the mine.

Three instrumentated cross sections of the dam allowed actual deformations and pore pressures to be compared with predictions, and the safety of the embankment thus reevaluated. Figures 13 and 14 present a general cross section, instrumentation, and data obtained in the operation of the dam.

4.3.2 Disposal of bauxitic clay in mined-out areas

The presence of high grade bauxite deposits in the eastern and central portion of Amazonia pushed mining activity towards this remote part of the country, where annual rainfall averages 2300 mm and mean temperature is 26°C.

The bauxite occurs in a matrix of highly oxidized kaolinitic clay that is removed, by washing, prior to shipping the ore. The material generated in this procedure has an initial solids content of 6%, a specific gravity of 2.97, and Atterberg limits of 52 (liquid limit) and 32 (plastic limit). During the first years of mining these tailings were deposited in a natural lake close to the industrial facilities. Pressed by the authorities, the mining company studied ten alternatives for tailings disposal, including building conventional dams and disposal in mined-out areas, deciding for the latter on an economical and environmental basis.

Moving of the washing plant to the plateau, where mining takes place, began in 1988. Deposition of tailings in the initial settling area will start in mid-1989. During each year, all tailings will be disposed in this specially built pond, in which they will consolidate to an estimated average solids content of 30%. On a continuing basis, a dredging system will pump thickened clay, in laminar flow conditions, into the final disposal areas (Carrier et al., 1985; de Mello and Carrier, 1987; de Mello et al., 1987).

All settling areas are located in mined-out areas and use, to the maximum extent possible, the spoil rows generated by the draglines in their stripping routine in order to minimize the construction costs of building the perimeter dikes to confine tailings on the flat plateau. Special procedures were developed by

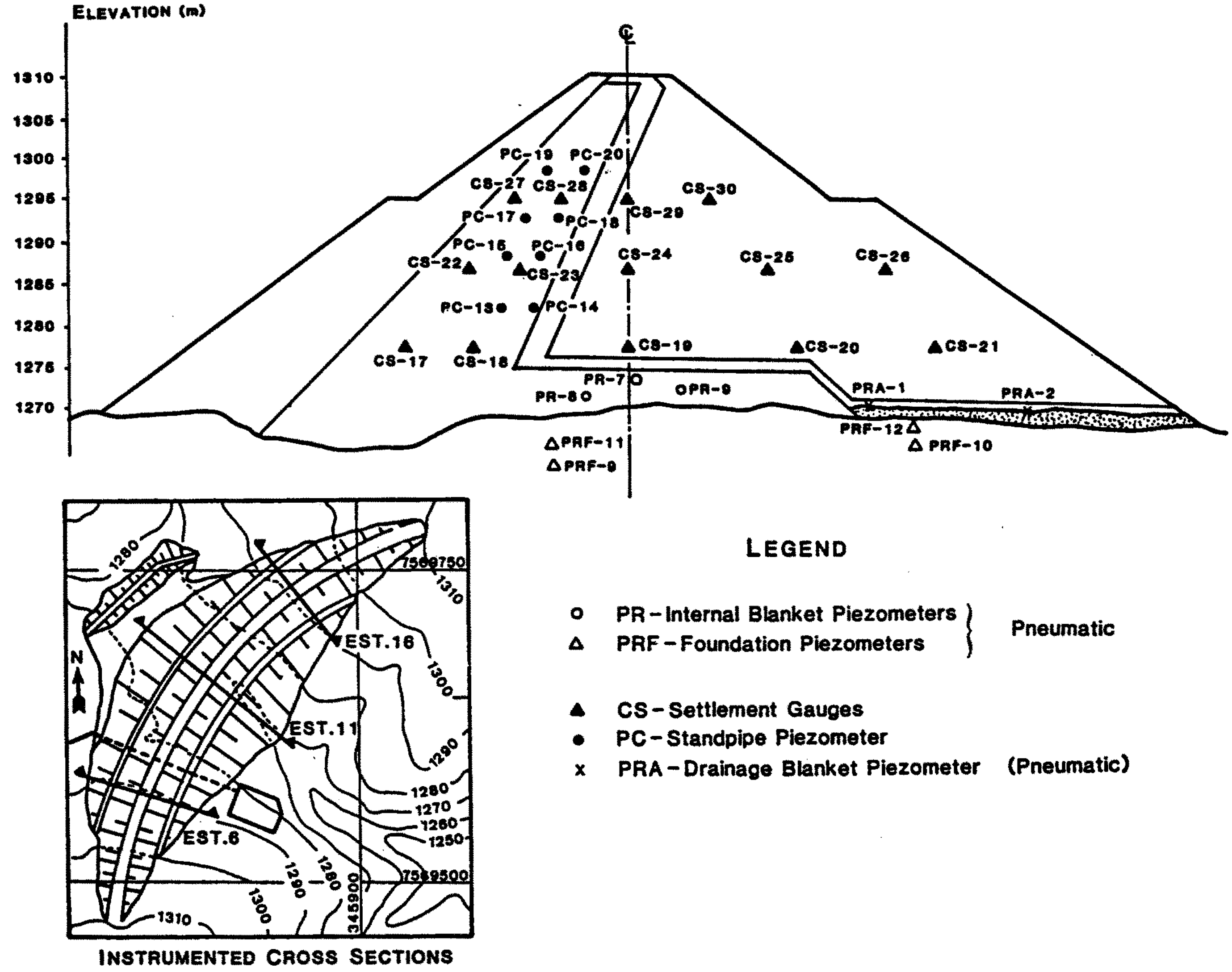


Figure 13. Typical Instrumentation of Mina do Cercado Tailings Dam

the mine personnel with respect to the operation of the dragline in order to maximize the difference in height of spoil rows produced by single and double casts.

The initial settling area is located in the vicinity of the industrial area. The cross section of its perimeter dikes was studied and optimized, as can be seen in Figure 15. The changes of cross section in the north wall are due to the foundation conditions, requiring that the entire dike be built with compacted material.

The final disposal areas are developed as mining proceeds, and are constructed with shaped overburden because they will only receive thickened tailings. All rain water caught by the disposal areas, as well as the water released by the consolidation of the clay, is incorporated in the water balance of the industrial facilities.

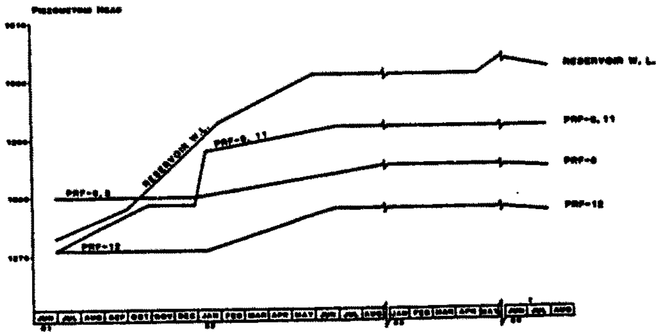


Figure 14. Foundation Piezometric Readings During Filling of Mina do Cercado Tailings Dam

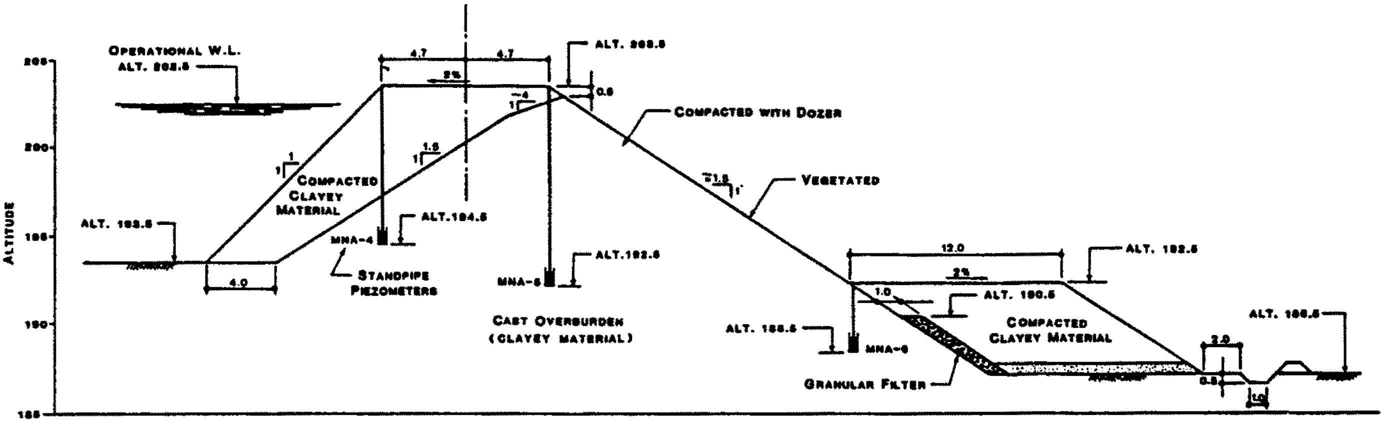


Figure 15. Typical Cross Section of the Initial Settling Area in the Mined-out Areas of Trombetas Bauxite Mine

This engineering solution has been found to be the least expensive among ten alternatives and fulfills all environmental requirements of the Brasilian legislation as specified by the CONAMA and DNPM, as well as some internal requirements of the mining company.

Consolidation predictions of the tailings in their final disposal areas indicate that in about two years after thickened disposal, all areas will be ready for commencement of reclamation. The available experience in the mine with reclamation of old disposal areas (Cardoso, 1987) will be used as a starting point for the development and optimization of local techniques.

4.3.3 Disposal and dam construction of phosphate tailings

Phosphate occurrence, mining, and beneficiation in Brasil is, so far, mainly concentrated to the region around the town of Araxa, in the state of Minas Gerais. Three different mining companies work in the area and all three of them are disposing of their tailings in a similar procedure (Whaler et al., 1978; Nieble et al., 1980; Bush et al., 1981, 1982, 1986; Bush, 1987).

The tailings produced in the beneficiation of the ore include non-plastic materials from the flotation and residual magnetite, as well as very plastic muds, with Atterberg limits around 80 (liquid limit) and 40 (plastic limit). Cycloning the magnetite and the tailings from the flotation plant produces a construction material that has allowed all six impoundments built so far to use a variation of the centerline method. The shear strength of the magnetite is reported to have a friction angle between 35° and 40° and a coefficient of permeability around 1×10^{-5} m/s. The underflow of the cycloned flotation tailings has a friction angle between 33° and 35°, sometimes reaching 40°, and a coefficient of permeability between 1×10^{-4} and 1×10^{-5} m/s.

A typical cross section of the dams is shown in Figure 16; a starter dam is built with local clayey soils to allow start of operation of the plant. After some time has elapsed, all underflow of the cyclones is deposited downstream and the overflow (Figure 17), as well as the muds, are deposited upstream. The material deposited in the downstream face of the dams is reworked with dozers to the final design slopes, densifying the non-cohesive material. With experience gained, dams up to 60 metres high are now under construction, with downstream slopes of 1V:2.8H.

Mangolim (1987) reports that piezometric readings taken in two of the mentioned dams indicate that the phreatic line intercepts the internal drainage system, resulting in a downstream slope free of pore pressures.

Special care is also taken with respect to the control of aeolic and water erosion in the downstream slope of the dams, which is accomplished through the proper surface drainage of each berm and planting of local grasses in a layer of topsoil specially spread over the slope.

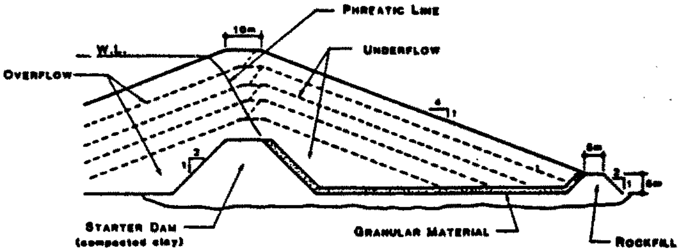


Figure 16. Typical Cross Section Used for the Disposal of Phosphatic Tailings (Whaler and Gifford, 1978)

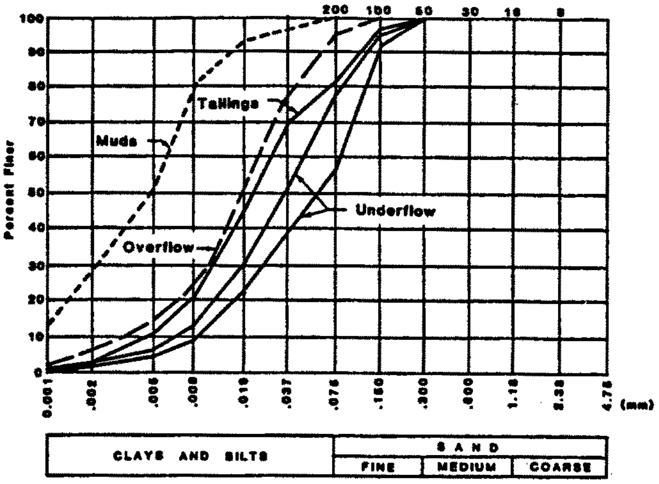


Figure 17. Grain Size Curves of Materials Produced During Beneficiation of Phosphatic Rock (Whaler and Gifford, 1978)

4.3.4 Failures in the disposal of iron ore tailings

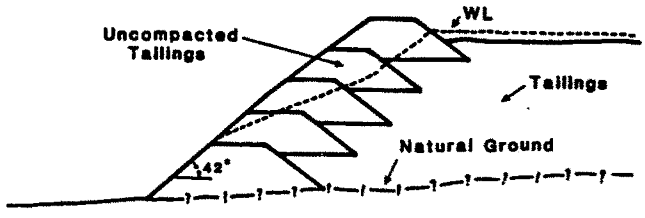
Tailings dams in operation in Brasil have generally had good engineering design and construction, but some have been built with little or no geotechnical engineering assistance at all.

The increase in need for storage capacity of some of these dams has caused them to surpass precedent experience, and some failures have occurred. Many other failures occurred because basic engineering principles and knowledge were not followed. In a review of 97 existing tailings dams in the Iron District of Minas Gerais, Mascarenhas (1983) reported that 33% were considered insecure by a technical committee that inspected them. Of the available published case histories, one is specially well-documented (Parra et al., 1987) and is worth being summarized.

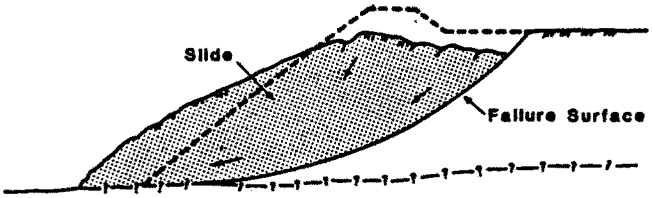
Tailings Dam at Fernandinho Mine

This iron ore mine is located very close to the highway that connects the capital of the state of Minas Gerais to the city of Ouro Preto. The 40-metre high dam had been stage-constructed for many years until 1984; since then, consolidated tailings were constantly removed from the reservoir, with front-end loaders and trucks, allowing the crest of the dam to be maintained about 2 metres higher than the tailings being deposited.

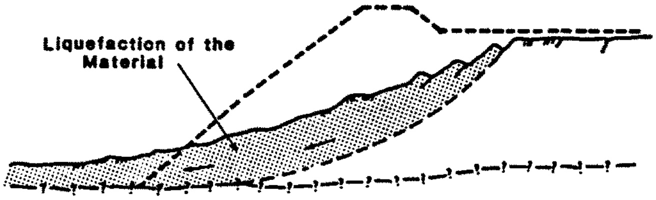
At the time of the accident, 3 trucks and a front-end loader were working at the crest of the dike, and were involved in the failure. The failure took place in two stages (Figure 18): first there was a smaller slide close to the right abutment, taking with it the equipment and workers. Immediately after, a huge noise was heard and the total failure of the dam occurred, generating a considerable mudflow. This mudflow involved a volume of 350,000 m^3 and its flow through the valley left impressive scars and allowed estimates of the velocity and of the viscosity of the material to be made.



(A) PRIOR TO FAILURE



(B) FIRST PHASE OF THE FAILURE "SLIDE"



(C) SECOND PHASE OF THE FAILURE "MUDFLOW"

Figure 18. Tailings Dam - Mina Do Fernandinho

The construction material and the tailings were a very fine silty sand, with some iron and mica particles (Figure 19). The cross section of the dam did not show any zoning with different materials and the downstream slope had an inclination of 42 degrees. Its foundation rested on quartzites and phyllites. The piezometric levels determined during the inspection of the dam, after the accident, were very high as can be seen in Figure 20.

The technical committee that inspected the failure, in its report, concluded that the accident occurred because the height and the slope of the downstream face of the embankment were not compatible with the shear strength and the pore pressures developed in the soil mass.

Vibrations induced by the earthmoving equipment in the fine loose cohesionless material may have triggered the failure of a slope already in critical condition. This critical condition may have been reached by the raising of the piezometric line in the dam, due to clogging of the natural drainage through the quartzites of the foundation.

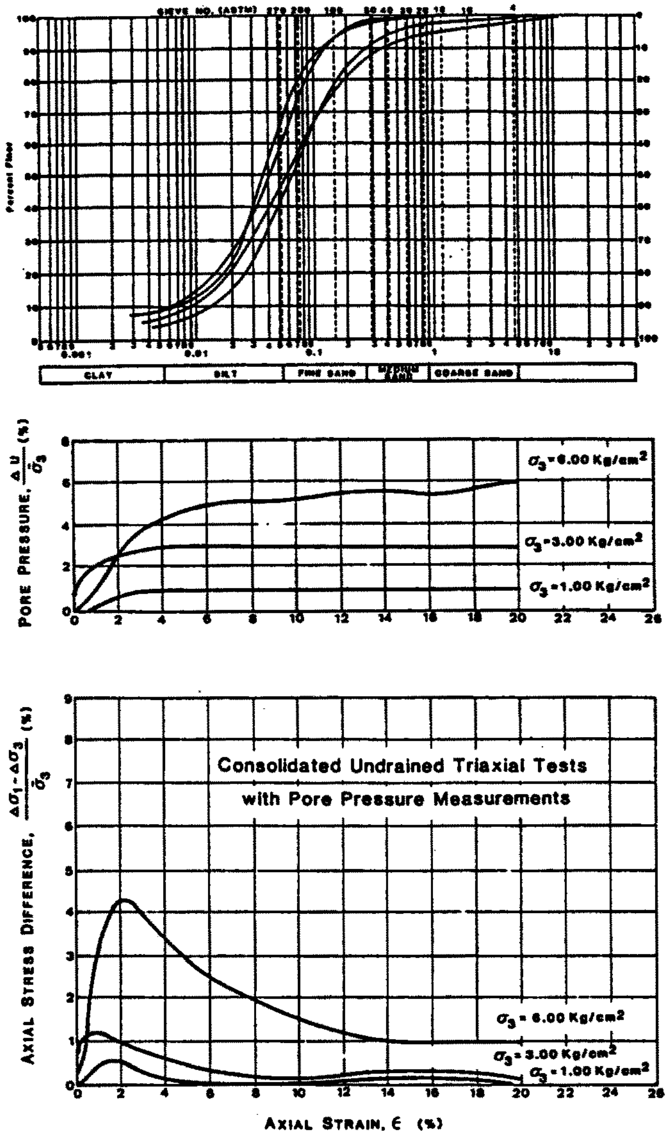


Figure 19. Tailings Dam - Mina Do Fernandinho - Grain Size Curves and Triaxial Tests

The density of the material as placed in the dam was low, and its void ratio was higher than the critical void ratio. Triaxial tests performed after the accident (Figure 19) showed a post-peak behavior in the stress-strain curve and a development of pore pressures that confirmed the hypothesis of liquefaction potential of the material prior to the failure.

4.3.5 Disposal of stripped overburden material

Many mines in Brasil are open pit mines and, depending on the type of ore, significant volumes of stripping material are generated. The proper and safe deposition of these materials requires sound engineering judgment in order to minimize costs of what is considered a non-profit activity.

In the past, many mines just dumped the stripping material in areas as close as possible to the pit. The natural topography of some mine districts in Brasil can be very steep and many pits excavate preconsolidated argillaceous materials (phyllites, argillites, etc.) which, when stress-relieved and exposed to the weather, deteriorate and generate instabilities and mudflows. This combination of features produced many impressive slides, some with casualties.

Many examples in the literature focus on the need for proper surface drainage and for consideration of the overburden as a material requiring construction specifications in order to fulfill its expected behavior during a large time span (c.f., de Mello et al., 1984; Barcelos, 1985; Ramos et al., 1987; Signer, 1987). Some areas are even reported to have had removal of saturated clayey material from the foundation of the spoil piles. Data from the instrumentation of sites with piezometers allow proper construction period analysis and may, in extreme events, control the rate of disposal of spoil in certain areas.

4.4 Concerns for future

As a developing country, Brasil faces enormous challenges in the near future; no doubt a proper analysis of impact on the environment due to geotechnical engineering activities will be demanded by society and the authorities.

The expanding industrial base of Brasil will require power, and although the potential for development of hydroelectric power is still very large, it is mainly concentrated in remote areas. Hydroelectric schemes in the Amazon region usually involve major reservoirs which in turn require environmental impact assessment studies for the flooded area, including water quality predictions, as some reservoirs in the area have already suffered problems of high concentrations of organic acids. Developing nuclear power plants is a possibility despite the fact that the population has consistently been opposed to it.

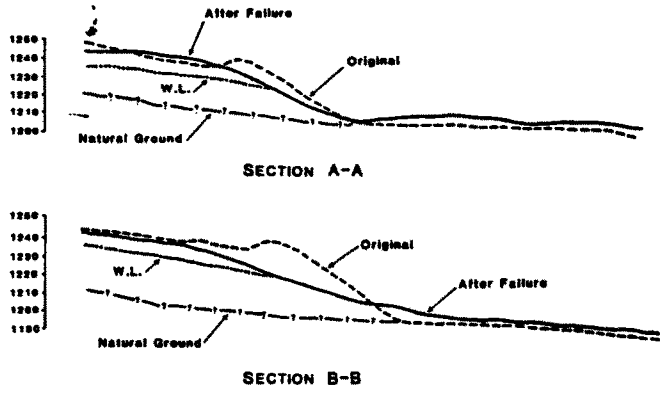


Figure 20. Tailings Dam - Mina Do Fernandinho - Cross Sections Before and After Failure

The mineral resources of Brasil are still very far from being known and developed; the beneficiation of these resources prior to export also seems to be a trend that will naturally develop. Major gold mining activities involve, in the studies of the beneficiation facilities and of disposal of their tailings, analysis of potential aquifer contamination through percolation of heavy metals and other components. The transformation of bauxite into alumina usually requires recycling huge volumes of caustic solution and the protection of the aquifer.

The conquest and development of the Amazon region will no doubt be pursued by the authorities, requiring roads, airports, power, services, and all other social needs to be planned and built, as well as all planned industrial development.

The proper disposal of toxic and hazardous wastes is a topic that will need all possible attention in the near future. This problem so far has not had the needed recognition and has been relegated to a secondary position. A recent major accident near the city of Goiania, State of Goias, occurred when capsules of cesium-137 were inadvertently opened by workers at a scrap yard, causing many casualties. The clean up operations generated wastes that required special disposal sites and technical studies were developed on an emergency basis.

5 SOUTHEAST ASIAN PERSPECTIVE

5.1 General

For reasons associated with the formation and membership of the Southeast Asian Geotechnical Society, the perspective in this paper is limited to Hong Kong, Malaysia, the Philippines, Singapore, Thailand and the Republic of China (Taiwan). The total land area of these countries covers about 1.18 million sq km and stretches for more than 2,400 km from east to west and more than 3,400 km from north to south. With a total population of more than 150 million, Southeast Asia has become the most rapidly developing region in the world during the past decade. Three of the countries (Hong Kong, ROC, and Singapore) have been recognized as the most important Newly Industrializing Countries (NIC) in the world. Thailand is rapidly catching up to join the rank.

Four of the countries belong to a political alliance, called the Association of Southeast Nations (ASEAN, the other members are Indonesia and Brunei). Environmental matters are discussed under the ASEAN Committee on the Environment and are also dealt with by the ASEAN Council on Petroleum. Each of the member countries has made important advances in quite different areas and there has been cooperation at the agency level among member countries, as in the case of waste water treatment. Of these four countries, the tiny city-state of Singapore has in many ways traveled furthest down the road of environmental control. Singapore has developed an umbrella environmental agency and a full set of legal provisions. The standards and procedures adopted are the most stringent in the region and very considerable investments have gone into providing physical treatment and other facilities, technical and management personnel, and matching financial resources.

The countries of Malaysia, the Philippines, and Thailand are roughly of the same order of physical size, resource endowment, and economic development, but Malaysia has only about one-half the population of the other two countries. In terms of legal provisions for environmental laws and regulations, the Philippines had an early start. However, the recent political and economic problems of that country have put the environmental program at a virtual stop. Thailand appears to lag behind in the formulation of an appropriate legal framework, although it is no less effective in achieving environmental goals. Malaysia has enjoyed a long period of economic growth and political stability and has made impressive achievements in its environmental program. An excellent treatise on environmental management in Southeast Asia has been compiled by Chia (1987). Much of the information described below on these four countries is taken from the articles written by Ong et al. (1987), Villavicencio (1987), Chia and Chionh (1987), and Setamanit (1987).

Hong Kong is similar to Singapore; it is essentially a city-state with no natural resources. The territory has the highest population density in Southeast Asia and a majority of the environmental problems are related to human-based activities. Although environmental protection legislation has only been enacted in the last decade, significant progress has been achieved in environmental management. Due to its geographic location and political relationship, there are important aspects of Hong Kong's environmental control that are affected by the policy and administration of its immediate neighbor, the People's Republic of China.

Taiwan is probably the most industrialized nation in the region and has a very well developed agricultural program as well. With a population of 19 million spread over less than 12,000 sq km of usable land, environmental problems have been escalating at an alarming rate. Although legislation regarding environmental control, such as water pollution control, was enacted more than 15 years ago, enforcement of these regulations has been no more than superficial. As in many other developing countries, there has always been a dilemma between the goals of environmental protection and those of industrialization and development. However, public awareness of the environmental problem has become a major driving force in recent years, pushing the government to allocate more investment to physical treatment and other environmental management programs.

5.2 Laws and regulatory bodies

5.2.1 Singapore

Singapore's policies on environmental

protection are set within an urban context. The primary objective is to provide "better environmental health services and control of pollution." Since the safeguarding of public health is a matter of priority, environmental impact assessments for large projects, including the international airport, the petrochemical plant (which is on an off-shore island), and the Mass Rapid Transit system, are not mandatory even though some investigation is made into possible environmental impact. In Singapore, managing the environment has been almost exclusively left to the government; there has been very little participation of private bodies in promoting environmental conservation. As a general rule, the Singapore laws on pollution control are premised on the principle that the polluter must bear the costs of pollution (Soon, 1982).

As a city-state, Singapore has the advantage of having a single-level government. The Ministry of the Environment (MOE), which was established in 1972, is the central unified authority on environmental control and management. The main legislation behind the work of the MOE is the Environmental Public Health Act of 1970, which has been expanded and amended many times since its first enactment. There are other government organizations which are concerned with environmental protection and enhancement. These are organizations charged with the physical development of the country, including the Housing & Development Board, the Urban Redevelopment Authority, the Jurong Town Corporation (where a large number of industries are concentrated), and the Port of Singapore Authority. Among the 17 Environmental acts and 55 Regulations, the following are of concern to the geotechnical engineering profession: Water Pollution and Drainage Act, 1975; Trade Effluent Regulations, 1976; Sanitary Plumbing and Drainage System Regulations, 1976; Sewage Treatment Plant Regulations, 1976; Surface Water Drainage Regulations, 1976; Factories Act, 1973; Building Operations and Works of Engineering Construction Regulations, 1977; Prevention of Pollution of the Sea Act, 1971; Amendment, 1976; Prevention of Pollution of the Sea Regulations, 1976; and Sand and Granite Quarries Act, 1974.

5.2.2 Malaysia

In recognizing the importance of environmental quality to mankind, a special chapter was devoted to addressing the issue of development and environment in the Third Malaysia Plan (1970-1975), which stated:

> "Environmental improvement and protection will receive the full attention of the Government in the planning and implementation of programmes in the TMP. It is vital that the objectives of development and environmental consideration be kept in balance so that the benefits of development are not neglected by the costs of environment damage."

The factors to be taken into account in Malaysia's overall environmental policy have been spelled out in the document as follows:

1. The impact that population growth and man's activities in resource development, industrialization and urbanization have on the environment;

2. The critical importance of maintaining the quality of the environment relative to the needs of the population, particularly in regard to the productive capacity of the land resources in agriculture, forestry, fisheries and waters;

3. The need to maintain a healthy environment for human habitation;

4. The need to preserve the country's unique and diverse natural heritage, all of which contribute to the quality of life; and

5. The interdependence of social, cultural, economic, biological and physical factors in determining the ecology of man.

The basic legislation for environmental control in Malaysia is the Environment Quality Act of 1974. This comprehensive Act provides a common legal basis to coordinate all activities on environmental control throughout the country. This Act gives the Division of Environment of the Ministry of Science, Technology and Environment the mandate and means to accomplish national goals in environmental protection. In addition to the basic Act, there are currently about 34 environment-related laws. Among which, the following are geotechnically-related: National Land Code, 1965; Streets, Drainage and Building Act, 1974; Forest Enactments, 1934; Mining Enactments, 1929; The Waters Enactments, 1920; Drainage Works Ordinance, 1954; Land Conservation Act, 1960; and Environment Quality Act, 1974.

5.2.3 Thailand

Problems of environmental deterioration were recognized for the first time in Thailand in its Third Development Plan (1972-1976), which resulted in the establishment of the Technology and Environment Planning Division within the National Economic and Social Development Board in 1975. In the Fifth Plan (1982-1986), there were for the first time explicitly a Science and Technology Plan and an Environment Plan in the overall development plan.

The first legislation on the environment was the National Environmental Conservation and Promotion Act promulgated in 1975. Under the Act, the office of the National Environment Board (NEB) was established. The NEB was transferred from the Prime Minister's Office to the Ministry of Science, Technology and Environment in 1979. The NEB is responsible for activities concerned with the conservation and promotion of environmental quality. It is charged mainly with the functions of policy formulation and planning. Since the NEB is not empowered to issue regulations or to enforce standards, it lacks substantive authority. The NEB's effectiveness thus depends very much on voluntary cooperation of other public agencies, although it is empowered to require government agencies, state enterprises and persons to submit documents and data concerning projects or schemes considered potentially dangerous to the environment. The NEB only has the power to recommend remedial measures to the Council of Ministers. There are many other government agencies which are directly responsible for enforcing the laws and carrying out effective environmental protection measures. These agencies include the Ministries of Health, Industry, the Interior, Communications, Agriculture and Cooperatives, the Department of Public Works, Local Administrations, and the Bangkok Metropolitan Authority. The number of agencies involved is large and the jurisdictional areas are not clearly defined in many instances, which unavoidably causes confusion and misunderstanding leading to inefficiencies in enforcement.

The most important piece of legislation on environment is the 1975 Promotion and Conservation of the Environmental Quality Act, which is quite comprehensive. The most powerful and effective measure lies in section 17 of the Act. Under this section, the Prime Minister, with the advice of the NEB, has the power to issue notifications in the Government Gazette prescribing the following: (1) Categories and magnitude of projects or activities which are required to submit Environmental Impact Assessments, (2) Standards of environmental quality which, by law, are not within the power and duty of any government agency, and (3) Methods to be used for checking environmental quality. The NEB has issued a Manual of Guidelines (1978 and 1981) for environmental impact assessment studies by development sectors including agro-industries, coastal zone development, dams and reservoirs, dredging and filling, highways, housing estates, human settlements, industrial estates, industries, institutions, nuclear power plants, offshore mining, oil pipelines, ports and harbors, mass rapid transit, thermal power facilities, and swamp and wet land reclamation.

There are more than 50 laws and regulations which are applicable to the protection of the environment. Those of particular importance to geotechnically-related environmental control include the Factories Act of 1969, the Underground Water Act of 1977, and regulations relating to building construction and human settlement.

5.2.4 Philippines

The major environmental problems in the Philippines are (1) The exhaustion and degradation of its terrestrial ecosystems, (2) The degradation of the coastal environment and ecosystems, and (3) Industrial pollution and the discharge of urban wastes into water courses, automobile and industrial exhaust in major cities, and deposition of solid wastes.

The Philippines' Congress enacted an environmental policy as early as 1964 with the establishment of the National Water and Air Pollution Control Commission, which was subsequently changed to the National Pollution Control Commission in the late 1960s. The Commission promulgates air and water quality standards as well as appropriate rules and regulations for compliance to these standards. In 1977, the Commission was given police power to strengthen its regulatory function. In 1973, a Task Force on Human Settlement was created to address the related problems of development, population, resources and environment. By the mid-1970s, environmental concerns started to take on a wider perspective, becoming concerned with all aspects of the natural environment, including land, water, minerals, all living organisms, and life processes. An Inter-Agency Committee on Environmental Protection was created in 1976. In 1977, the National Environmental Protection Council was created with much wider overall power and responsibility. As the result of studies carried out by the Council, two important pieces of legislation were enacted. They are the Philippine Environmental Policy 1977 (P.D. 1151) and the Philippine Environmental Code (P.D. 1152).

5.2.5 Hong Kong

The environmental protection program in Hong Kong has been developed progressively over the past decade. It was started in 1977 with a small central unit, the Environmental Protection Unit. The unit was charged with coordinating the various environmental protection activities carried out at that time by many different departments of the Government. The work of the Unit was hampered by the absence of objective data on the environmental situation in Hong Kong and by the lack of sufficient qualified and experienced staff to develop the new legislation and improved environmental programs that were required to deal with the increasing pressure on Hong Kong's Environment. The Unit was strengthened and expanded into the Environmental Protection Agency in 1982 and then to the present Environmental Protection Department (EPD) under the Secretary of Health and Welfare in 1986. The EPD is responsible for formulating policy, monitoring levels of environmental pollution, establishing new programmes for environmental involvement, planning new sewerage schemes, as well as new facilities for the treatment and disposal of sewage and solid waste. It also implements controls contained in the major environmental protection Ordinances, coordinates Environmental Impact Assessment of major developments, and provides advice on the environmental implications of major developments. Today the EPD has a total staff of 507 (Reed, 1987; HK EPD, 1986). In addition, there are a number of other government departments which are responsible for the design and construction of installations for the collection, treatment, or disposal of wastes. In 1986, administrative requirements were placed on all projects in the public works program that they must be subjected to environmental review.

In Hong Kong, there is no comprehensive legislation on environmental protection. The laws controlling the Hong Kong environment are comprised of both specialized and ancillary legislation. This has resulted in a fragmented approach. Even with the centralized EPD's increased responsibilities, there are still many pollution sources which remain outside the control of this body (Downey, 1987). At present, there are three pieces of legislation on environmental control: Waste Disposal Ordinance of 1980, the Water Pollution Control Ordinance of 1980, and the Air Pollution Control Ordinance of 1983. There are 28 other ordinances and regulations relevant to the control of the environment in Hong Kong. Among them, the Building Ordinance, Public Reclamation and Works Ordinance, Dumping at Sea Act of 1974, and Waterworks Ordinance are of particular relevance to the geotechnical profession.

5.2.6 ROC (Taiwan)

As in many other developing countries, environmental protection did not receive much attention in the ROC before the 1980s due to emphasis on the development of industries, natural resources, and infrastructures. With the rapid economic development and improvement of living standards, both the government and the people have become aware of the rapid deterioration of the environment. Although legislation on water pollution and waste disposal were enacted as early as 1974, enforcement of these laws and regulations was much less stringent than might be desired. This is primarily due to the following factors: (1) Fragmentation and unclear jurisdictional areas of government agencies charged with the enforcement of environmental protection, (2) Lack of public awareness and, thus, limited support from the public, and (3) Misconception about conflict between economic development and environmental protection and improvement.

Although Taiwan is of relatively small size, its political structure is quite complex. There is a central government (the Cabinet), a provincial government (Taiwan Province), two special cities (Taipei and Kaohsiung), and a network of local governments. In the 1970s, environmental control and management were vested in the local governments and other government agencies which are directly responsible for various aspects of development. Although there were a number of laws and regulations on environmental control, actual enforcement was very poor. In 1981, the Environmental Sanitation Bureau, which was established in the 1970s, was expanded into the Bureau of Environmental Protection under the Administration of Health and Sanitation of the central Government. In the following two years, Environmental Protection Departments were established in Taipei City, Kaohsiung City, and Taiwan Province. In 1987, the Bureau of Environmental Protection was expanded and elevated to Environmental Protection Administration (EPA) directly under the Cabinet. The EPA, with an approved staff of 347, is responsible for formulating policies and regulations for environmental protection and control, supervising and reviewing environmental impact assessment studies, planning new schemes and new facilities for the treatment and disposal of wastes, and coordinating and supervising activities of the city and provincial Environmental Protection Departments.

Although the regulations for Enforcing Environmental Impact Assessments (EIA) were only officially proclaimed in October 1985, many major development projects in Taiwan prior to that had EIA studies. According to the resolution adopted by the Cabinet on October 13, 1983, all major development projects of the government (including development of national parks) and of private industries which may cause environmental pollution must carry out an EIA study as part of the conditions for approval.

Besides the legislation governing the formation, function, and jurisdiction of the various environmental protection agencies and that on EIA as described above, there are 49 acts and regulations on environmental control and more than 20 related acts and codes. Of particular importance to the geotechnical profession are the Water Pollution Act of 1974 (amended 1983), Waste Disposal Act of 1974 (amended 1980, 1985), Waste Disposal Regulations for Taipei City (1975), for Kaohsiung City, and for Taiwan Province, and the Slopeland Conservation Regulations 1986.

5.3 Current practice

5.3.1 Water pollution

The close relationship between the maintenance of public health of the population and keeping the water clean for consumption and for domestic use as well as for the need to obtain clean water for industrial and commercial use demands careful control of pollution of the water resources. Many countries derive their water supply not only from surface water (reservoir, rivers, streams, and canals) but also from underground aquifers. Contamination or pollution of the underground water due to either industrial pollution or saltwater intrusion caused by excessive deep well pumping is becoming a serious problem in many countries in Southeast Asia. Protection of surface waters deals with the control of discharge from industrial, commercial, and domestic premises as well as from agricultural sources. Except for siltation of the water courses due to soil erosion or dumping of construction wastes, problems of pollution of surface water are not closely related to the geotechnical profession.

Thailand and Taiwan have experienced special problems of land subsidence due to deep well pumping from underground aquifers. In the Thai capital city of Bangkok, water is pumped from underground at a rate of about 1,140,000 m^3/day. Due to this heavy extraction of water, the piezometric pressure of subsurface water has been dropping at a rate of about 2.4 m per year, which has caused land subsidence of about 40 to 60 cm within a radius of about 20-30 km. The aquifers at shallow depths have become heavily contaminated by seawater intrusion. The Underground Water Act was promulgated in 1977 to stop uncontrolled extraction of underground water. Although the rate of subsidence in the Bangkok Metropolitan Area is reported to be decreasing as shown in Figures 21 and 22, which compare the subsidence rate in 1981 and 1985, the problem of subsidence appears to be spreading further from the Bangkok area due to the expansion of industries in the surrounding regions, with an estimated affected area at more than 1,000 sq km (Bangkok Post, 1987).

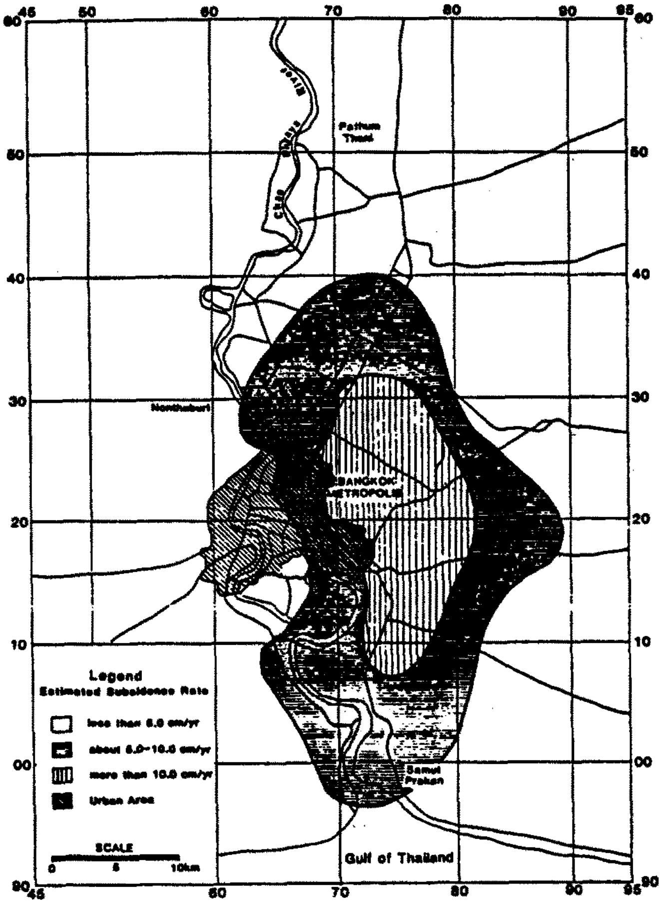


Figure 21. Rate of Subsidence in Bangkok Area in 1981

Similar problems exist in Taiwan. Deep well pumping has been used to augment water supply in the Taipei Basin since 1946. The piezometric pressures in the various water bearing layers has been dropping continuously, up to 2 to 3 m per year. As a consequence, serious regional subsidence has occurred. Figure 23 shows the isopleths of total subsidence in the Taipei Basin over the 21-year period from 1955 to 1976. There were 2.98 sq km of land area with subsidence exceeding 2 m, and 50.68 sq km with subsidence more than 1.5 m, which is about 21 percent of the total land area in the Basin (Wu et al., 1976). With effective and stringent control of well pumping by the government authorities in the past 15 years, the problem of subsidence settlement has been greatly reduced. The maximum rate of subsidence in the Basin has decreased from more than 20 cm per year to less than 2 cm per year. However, this problem becomes much more serious along the coastline of southern and central-western parts of Taiwan due to the rapid development of the fishery cultivation industry, which requires a large quantity of fresh water to be pumped from the subsurface. The most serious areas had already subsided below mean sea level with subsidence reaching more than 3 m. Although there are many laws and regulations that are related to the development of coastal regions, fragmentation of responsibilities and functions of too many governmental organizations involved resulted in this serious coastal environmental problem.

5.3.2 Solid waste disposal

The two main types of solid wastes are sewage and refuse. In most of the countries, these two types of solid wastes are often handled by different agencies. Sewage is usually the concern of the sewerage department of local government and disposal of refuse is often the concern of the environmental protection agency, if there is one. In Singapore at the end of 1985, some 90 percent of the population had modern sanitation. There are 6 sewage treatment works, 1,019 sewage treatment plants, 124 pumping installations, and 1,936 km of public sewers. Treated effluent is discharged at a safe distance of about 1.15 km

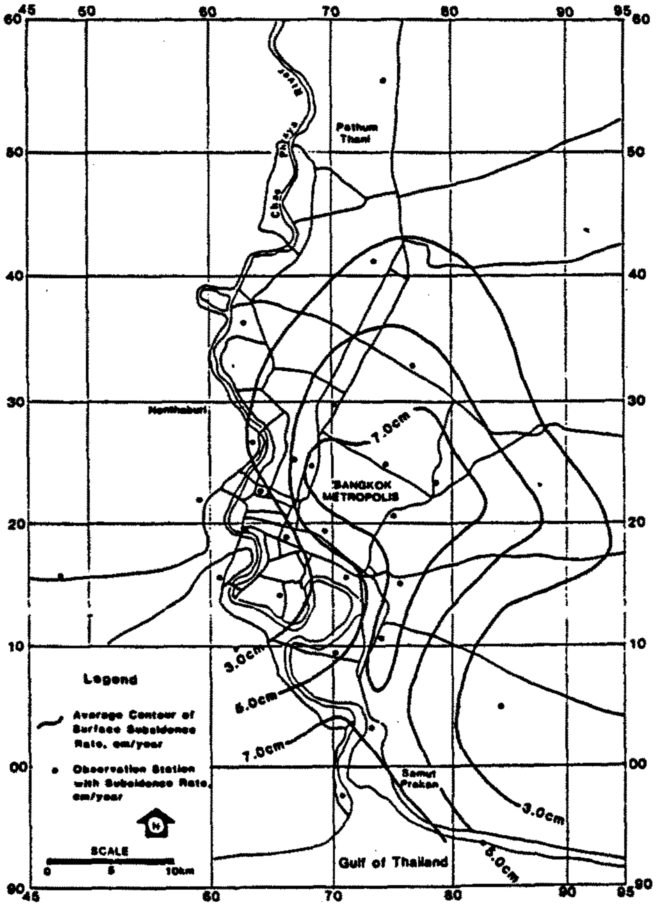


Figure 22. Rate of Subsidence in Bangkok Area in 1985

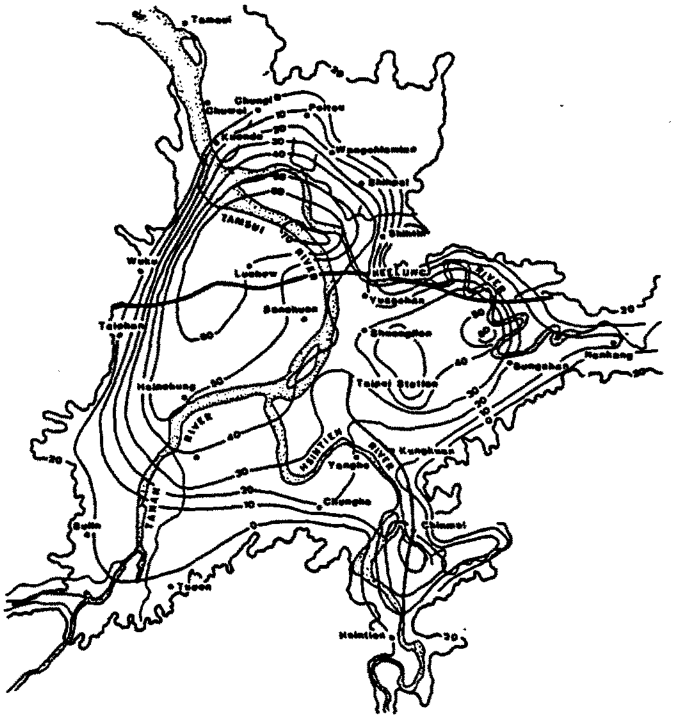


Figure 23. Subsidence in Taipei Basin, 1955-1976

from the shore. Some of the liquid effluent is recycled and sold as industrial water. The main sources of refuse are households, industries, institutions, and food markets. The amount of refuse per person per day was estimated to be 1.3 kg in 1982 and the amount is projected to increase to 1.7 kg by 1990. Refuse in Singapore is disposed either by dumping in sanitary landfills or by incineration. At the present, there are three dumping grounds but two of them will end their life span by 1990s. In a land-scarce country like Singapore, incineration of solid refuse has proved to be cost-effective and also more hygienic. At the present, there are two incinerators in Singapore, one with a capacity of 1,600 tonnes per day, and the other 2,000 tonnes per day. A third one is now under design.

In Malaysia, only about 20 percent of the urban population is using facilities connected to a community water-borne sewerage system. There is an estimated 3.7 million tonnes of waste being generated and disposed of annually. About 44 percent of the solid waste is disposed of by dumping at sanitary landfills. In Peninsular Malaysia, an average of 0.01 hectare of land per 1,000 people is currently used for municipal waste disposal. Due to running out of available land for waste disposal, some states utilize mining land, and others use reclaimed coastal land. The other forms of disposal include about 24 percent by open burning, 1 percent by incineration, and the remaining by direct disposal into rivers and oceans as well as by haphazard manner. These latter methods of disposal in fact create other forms of environmental pollution.

The most common waste disposal practices in the Philippines are dumping and burning. Indiscriminate open dumping on land, in inland water bodies, and the sea are the rule rather than the exception. There are very few controlled sanitary landfill sites in the country. In Metro Manila, with a population of six million people, 2,650 tonnes of garbage are produced every day. There are 9 open dumps which are all privately owned and not very well controlled.

In Thailand, the waste disposal problem is no better than that in Malaysia and the Philippines. There is a great lack of equipment for collection and treatment of refuse and all solid wastes. Control of the disposal also poses serious problem in the country.

In 1986, the amount of solid waste generated from various sources in Hong Kong averaged some 8,100 tonnes per day. It is estimated that an average increase of about 10 percent per annum in total waste will occur due to increase in population and its affluence in the territory. Incineration and landfilling are the two main methods for waste disposal. There are at present three incinerators and four landfill sites currently in use. The three incinerators treated some 2,420 tonnes per day of waste in 1986 which is about 26% of the total waste. The remaining 70 percent of the waste as well as the ashes from the incinerators and the 4 percent composite rejects are disposed at the four landfill sites which have remaining lives of only 1.5 to 3 years. The Hong Kong Government is now planning to have two of the world's largest solid waste disposal landfills operating by the early 1990s. An estimated 0.4 billion US dollars will be committed over the next 20 years to the two new landfills at the outskirts of the territory. The two sites, with areas of 57 and 110 hectares, will be capable of accepting more than 80 million tonnes of waste. For the design of the two new landfills, leachate will be controlled by lining the site with an impermeable layer of natural or synthetic material. The contained leachate will be collected and treated. The gas produced from decomposing landfill materials will be either vented to the atmosphere and dispersed or collected by a gas well system and burnt on site (Hong Kong Environment Protection Department, 1986).

According to the statistics compiled by the Taiwan Government (Cheung, 1985), the amount of solid refuse collected in 1980 was about 8,740 tonnes per day. The amount increased to 13,954 tonnes per day in 1986, and it is projected that by 1990, the amount will be 19,200 tonnes per day with an annual increase of 7 to 9 percent. The average per person per day is about 0.6 kg, 0.77 kg, and 0.9 kg, respectively. At present, about 98 percent are disposed at 296 sanitary landfills and dump sites with the remaining 2 percent being treated at 4 incinerators. Among the 296 landfill and dump sites, only 3 were properly designed. The rest did not have proper engineering design before use and at the majority of the sites, the refuse was not compacted. These sites are creating serious environmental problems. In view of the serious problem of waste disposal, the Government has included Municipal Waste Disposal as one of the 14 major economic development projects of the country. In principle, incinerators will be constructed for solid waste disposal in all municipalities having a population greater than 300,000. In rural areas and in municipalities where land is not too difficult to acquire, sanitary landfills will be utilized. Up to 1993, there will be 23 new incinerators with a total capacity of 8,815 tonnes per day at an estimated cost of 760 million US Dollars. A large sum of investment will also be put into new and improved sanitary landfills at 251 sites. By 1993, about 40 percent of the solid waste will be handled by incinerators. The total budget for Environmental Protection in the next ten years will be on the order of one trillion NT Dollars, or about 35 billion US Dollars.

5.3.3 Industrial waste disposal

Although in the Southeast Asian region there are some laws or regulations governing the disposal of industrial wastes, both non-toxic and toxic, there is a general lack of strong enforcement. Contamination of groundwater aquifers, although recognized in most of these developing countries, has received very little study and monitoring, not to mention control and remedial measures. This is probably due to the fact that groundwater pollution is not visually obvious, as is pollution caused by refuse disposal, surface water pollution, and air pollution. The governmental authorities tend to give a lower priority without sufficient in-depth consideration of the long-term effect on the quality of human life.

Control of industrial waste disposal in Singapore has been quite successful due to its small size and stringent government regulatory enforcement. The control is primarily on the quality, or treatment level of effluents discharged into surface water courses, including rivers and reservoir catchments. Clean up of two major river basin catchments, i.e. the Kallang and the Singapore River Basin, was completed in 1987.

Palm oil and rubber are the two major industries in Malaysia, which is among the top producers in the world. At the end of 1983, there were 210 palm oil mills in Malaysia producing about 4 million tonnes of palm oil per year. About 5.0 m^3 of palm oil mill effluent are generated for every tonne of palm oil produced. Although non-toxic, the effluent is highly polluting. It has a BOD content of 25,000 mg/l, which is about one hundred times that of sewage. The total BOD load generated from the palm oil industry is equivalent to that produced by a population of 24 million. Another major industry, the rubber factories, generates about 90,000 m^3/day of wastewater with a BOD load of approximately equivalent to 4.2 million population. With the introduction of strong laws and promotion of research on treatment technology, pollution problems caused by these two industries has been greatly reduced. For other industrial wastes, there are two standards governing the discharge of industrial effluents. Similar to the control of palm oil and rubber industries, all existing control standards are related to effluent discharge into surface water. There is no legislation controlling contamination of groundwater caused by disposal of untreated effluent disposed onto land.

The 1979 statistics showed that the estimated total wastewater volume from the manufacturing industry in Malaysia was 123.6 million m^3 per year. The estimated BOD load came to 37,250 tonnes/year or 125 tonnes/day. This was equivalent to approximately 2.48 million population (total population in Malaysia in 1980 was 14 million). The figure is expected to be much higher today.

The Philippines has abundant surface water resources, which comprise 419 principal rivers, seven major river basins, six major and 52 minor lakes, and vast swamplands. Despite the enforcement efforts of the Government, some 49 of the rivers are dead due to pollution from effluent discharge of industrial factories, domestic wastes, and water-based activities. Sugar mills, distilleries, pulp and paper mills, coconut-drying factories, and vegetable oils and food manufacturing industries are the major sources of industrial pollution.

Similar to most other developing countries, the industries in Thailand are small to medium in size. The problems that have prevented effective control and abatement of environmental pollution arising from industrial activities are found to stem from both economy and technology. With the introduction of the Royal Decree which created the Industrial Estate Authority of Thailand (IEAT), four major industrial estates have been successfully established for small and medium sized factories. Centralized waste treatment facilities and disposal are provided at these estates which can effectively control the industrial waste pollution. In the last two years, more private owned industrial estates are being developed. The Government is given encouragement and incentive to these developments which have effective environmental control facilities.

In Hong Kong, new laws and regulations, including the Water Pollution Control Ordinance aimed at controlling the bulk of sewage and industrial effluents, and the Waste Disposal Ordinance which controls the disposal of agricultural waste and toxic industrial waste, were being brought into full effect in April 1987. Industrial discharges into waters are allowed either by license which normally specify the permitted volume or rate of discharge and quality, or by exemption under condition. The major industries in Hong Kong are small and medium sized light industries including food manufacturing, textile, beverage, basic metal, repair, laundries, photographic processing, leather manufacturing, paper, chemical, metal products, and non-metallic mineral products.

The annual production of industrial wastes in the ROC amounts to 21 million tonnes which is about 5.25 times the amount of municipal refuse. About 85 percent of these wastes are "self-treated" by the industries who generate these wastes. Although there are laws and regulations concerning control of industrial wastes, such as Regulations of Industrial Wastewater Management, and Regulations Governing the Storing, Cleaning and Treatment of Industrial Wastes and Facility Standards, the management of industrial waste control has been poor. A large amount of the industrial wastes is either disposed as ordinary wastes and refuse, or abandoned indiscriminately without proper treatment. In addition to the wastes generated by fisheries, farms, mines, construction sites, ship-building industry, chemical plants, etc., there are thousands of tonnes of fly ash produced by the power plants daily, 500 tonnes of sludge from water treatment plants, and 110 tonnes of used engine oil from the 8 million motor vehicles and motorcycles.

5.3.4 Toxic and hazardous waste disposal

The existing facilities for disposal and handling of toxic and hazardous wastes in the Southeast Asian countries are generally unsuitable and inadequate. Considerable amounts of such wastes are being disposed of indiscriminately and pose long-term environmental hazards. A study has been carried out in Malaysia to help formulate policy guidelines on the appropriate waste management strategy for hazardous wastes, including the collection, treatment and disposal of such wastes. A national committee on toxic and hazardous waste disposal has been formed to institute follow-up action on the study.

In 1985, the Hong Kong Government commissioned an experimental study to develop proper procedures and guidelines for co-disposal of chemical wastes with municipal wastes at landfills. The applicability to co-disposal relies on the capacity of municipal waste to absorb, retain, and in some cases break down the toxic components. The capacity depends on the moisture content and the physical nature of the wastes as well as temperature and rainfall. The experiment includes both laboratory study and pilot scale test cells at the Junk Bay Landfill site. As shown in Figure 24, four test cells were constructed with soft fill materials, each cell being 400 m^2 in area, that were raised to a height of 10 m in 5 stages. The cells were lined with a 2.5 mm thick high density polyethylene sheet at the base for containment of the leachate. The cells were filled with refuse and compacted. One of the cells was designated as control and the other three cells were selectively filled with chemical wastes including tannery off-cuts, oily waste, paint waste, solvent waste, boiler grit, and digested sewage sludge. The behavior of the test cells are regularly monitored by collecting leachate and gas and settlement measurement. The study is expected to be completed in late 1988 (HK EPD, 1986).

From 1951 to 1980, the number of industrial factories in the ROC increased more than ten times from 5,622 to 62,474. Accompanying the accelerated progress in industry was the tendency of factories to abuse, misuse, and overuse chemical materials. There are approximately 3 million tonnes of toxic wastes produced by the industries annually. This amounts to an average of 0.15 tonne per year per person. Among the various industries, the basic metal industry produces the largest quantity of toxic wastes (about 38% of the total amount), followed by the electronic and electric industry (27%). Most of the wastes which cause environmental concern result from either imperfect processing or improper disposal.

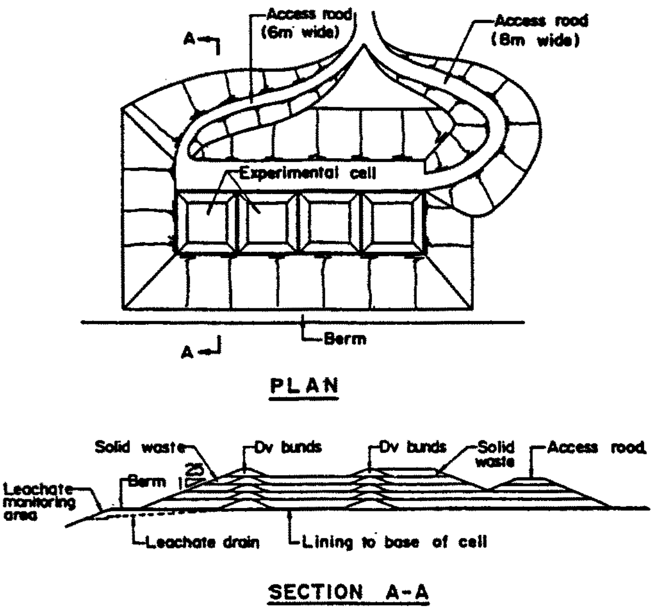


Figure 24. Arrangement of Co-disposal Test Cells - Hong Kong

To solve the problem and to prevent the toxic chemicals from further contaminating the environment, the Solid Waste Disposal Act Amendment was approved in November 1985. In 1987, programs for the control of hazardous wastes were adopted by the Cabinet. Polychlorinated biphenyls, heavy metals, and pesticides are listed as hazardous wastes of the first priority. The Environmental Protection Administration is now carrying out a nation-wide project to build a national information system for chemical management to readily reflect information of toxic chemicals and to prevent occurrence of chemical disaster (i.e., the An-Ching Project - The Data Base System for Toxic Chemical Control Project). Approximately 6,000 frequently used toxic chemicals and over 50,000 factories are to be included in this data base.

5.3.5 Mining wastes

Problems of mine tailings are of concern in the Philippines, Malaysia, and Thailand. Mining requires extensive use of land, air, and water. Mine development activities such as excavation in open-pit mining, block-caving, ground preparation which includes the construction of roads, buildings, and other infrastructures, inevitably encroach on a large scale upon the environment. Problems regarding water arise as a result of the large volume of mine wastes and tailings generated in the process of extracting the minerals. Tailings are consigned to tailing ponds and dams. In the event of a typhoon and heavy rainfall, these retaining areas can be washed away and huge quantities of tailings find their way into rivers, resulting in the deposition of large quantities of mine wastes in the water courses and surrounding lands. This silting process results in the burying of prime agricultural lands, destruction of aquatic life and reduction of river flow regimes.

In the Philippines, a total of about 226,000 tonnes of tailings are generated per day by 29 mines in the country. This is equivalent to 84 m^3/day, which becomes a potential threat from siltation of major river ecosystems and agricultural land.

In Malaysia and Thailand, tin mining is the major mining operation. Tin mine dredging causes increased turbidity in the water courses, which in turn causes substantially accelerated rates of sedimentation and changes in the hydrological flow. All of these effects could lead to the degradation of mangrove communities which are located in the vicinity of the tin mining operations. The other major problem is caused by the erosion of tin mines and tailing disposal areas. The fluvial transport and deposition of the eroded sediments cause accelerated sedimentation in the channels of water courses and pollute nearby beaches with mud and slimy deposits. For the large majority of tin mine operations in these two countries, very little engineering design was employed in control of the tailings.

5.4 Issues for the future

Being one of the most rapidly developing regions in the world, particularly in terms of industrial development, there are many environmental issues which the Southeast Asian countries are facing and must resolve in the coming decade. The environmental problems can be broadly divided into two main groups, namely, problems arising from development and exploitation of the natural environment and resources, and problems arising from the utilization of materials and energy resources. In both groups, degradation of the environment is the problem, and preservation and improvement of the environment are the issues. Many of the problems may not have direct relationship to geotechnical engineering, whilst many others are of great concern to the geotechnical profession.

For the Southeast Asian countries, the following areas particularly require the attention and participation of geotechnical engineers:

1. There are already many laws, regulations, and guidelines for environmental control and management. It, however, appears that there is a lack of codes of practice relating to environmental geotechnology.

2. Effectiveness of environmental control laws and/or regulations not only needs effective enforcement but also public awareness. Environmental consciousness and awareness should be a part of education for the geotechnical profession.

3. A proper guideline and code of ethics needs to be developed for the geotechnical profession, so that environmental issues are taken into consideration seriously during the entire process of the engineering work and becomes an integral part of the planning, design, and construction activities.

4. In countries like Malaysia, Thailand, the Philippines, and to certain extent the ROC, extensive study and careful planning are needed for construction of controlled landfills.

5. The expanding industrialization of the Southeast Asian countries will require more energy resources. Development of hydropower in most of the countries appears to be limited. The use of nuclear power will become inevitable despite the fact that there is strong opposition from the environmentalists. The geotechnical contribution to both developing nuclear power plants and to the disposal of nuclear waste cannot be overemphasized.

6. Proper geotechnical utilization of industrial wastes including solid waste for land reclamation and utilization of by-products such as fly ash from the fossil power plants will be one of the important areas of activity.

7. Control of toxic and hazardous wastes has not received sufficient attention in the past years. Contamination of groundwater due to environmental pollution will become a very serious problem in the near future. Joint efforts of geotechnical engineers and hydrogeologists are urgently needed to identify the problem and to find solutions for rehabilitation of the underground water regime.

8. Most of the environmental impact assessment for major development projects were carried out with little input from geotechnical engineers. Attention must be given to the effect on the environment caused by geotechnical activities and appropriate solutions must be found to reduce the problem.

6 CONCLUSIONS

In the preceding pages, we have summarized the current thinking regarding environmental impact, from the perspective of America, Brasil, and Southeast Asia. Despite differences in geography, politics, economics, culture, etc., the following broad themes have emerged:

1. People in general, and geotechnical engineers in particular, among other professionals, are very concerned about the environment, both locally and internationally.

2. The impact of natural forces and cycles on humankind is still very important and will continue to require the expertise of geotechnical engineers.

3. Landfilling of municipal, industrial, and hazardous wastes is probably a temporary solution. In the future, these wastes will likely be reduced, recycled, incinerated, or chemically stabilized. Geotechnical engineers will have less and less to do with these wastes as mechanical and chemical engineers develop alternative solutions.

4. Closure of old hazardous waste facilities will continue to occupy geotechnical engineers. But the emphasis will be on site characterization; remediation will be accomplished by non-geotechnical methods.

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Abbreviations:

ASCE: American Society of Civil Engineers
FIPR: Florida Institute of Phosphate Research
GPWD '87: Geotechnical Practice for Waste Disposal '87, Ann Arbor, ASCE, ed. by R.D. Woods
ICSMFE: International Conference on Soil Mechanics and Foundation Engineering
NASA: National Aeronautics and Space Administration (United States)
PCSMFE: Panamerican Conference on Soil Mechanics and Foundation Engineering
SBRDRIM: Symposium de Barragens de Rejeitos e Disposicao de Residuos Industriais e de Mineracao, Rio de Janeiro, 1987
SCMPV: Sedimentation Consolidation Models, Prediction and Validation, San Francisco, 1984, ASCE, ed. by R.N. Yong and F.C. Townsend
SSMHSR: Symposium on Surface Mining, Hydrology, Sedimentology and Reclamation

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