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Environmental Geomechanics - General Report
The Leading Role of Geotechnical Engineers in Environmental Engineering

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Summary This paper provides a general discussion of the role of the Geotechnical Engineer in Environmental Engineering. In the context of this paper, environmental engineering refers to those environmental engineering projects which have a strong 'geo' component. These types of projects include contaminated soil and groundwater assessment and management, solid waste landfills and mine site rehabilitation. In reality, geotechnical engineers are facing competition from other forms of engineers and scientists for the lead role in multi-discipline projects of this type. Geotechnical engineers are however, in a uniquely sound position to conceptualise the problems that need to be solved and to assemble teams of scientists and engineers to deliver successful environmental project outcomes. Geotechnical engineers do however, need to respond to the needs of designing to meet specific environmental quality objectives, rather than designing to a prescription or to some indirectly related criteria, such as soil permeability.

The papers included in this session are by geotechnical engineers and others who have seized upon these interesting challenges. The papers fall broadly into two groups. The first group are papers which are essentially dealing with the engineering challenges of re-using land disturbed by mining. The second group of papers deal with chemicals and the environment. In particular, they deal with "path-way" component of the "source - pathway - destination" problem which is at the core of most geo-environmental problems to be solved. Some brief comments on each of the papers are provided.

1. INTRODUCTION

Over the past decade, it has been interesting to watch the evolution of geotechnical engineers into environmental engineers. Indeed, the traditional university degree titles of Electrical, Chemical, Mining, Mechanical, and civil engineering have expanded to include Geological engineering and, in recent times Environmental engineering. The debate about of what might be considered a "pure" discipline of engineering is interesting and is one which will evolve with time in accordance with the changing priorities of our society. It is clear, however, that there are increasing demands on engineers to prove that our modifications of the earth's surface do not impact in an unacceptable way on our environment. Of primary importance to our society is the quality of their air, their drinking water and their food. But society is now also realising that protection of resources such as groundwater and soil and all of our natural eco-systems is also required for us to develop the earth in a sustainable way.

The skill base possessed by geotechnical engineers is an excellent one for developing and understanding the issues involved in geo-environmental problems. Usually, at the core of the problems involving contaminated soil, contaminated groundwater and waste storage facilities, is the "source-pathway-destination" problem. The source of contamination is often contaminated soil, solid waste or liquid waste. The pathway for migration of contamination, which we, in our profession are most often concerned with is migration through man-made layers and natural geological formations.

The "destination" part of the problem is sometimes overlooked by geotechnical engineers. However, it is this "destination" that is the driving force in the whole equation as it is at this "destination" that certain environmental quality objectives or health objectives need to be met. The "destination" may be a creek, an ocean, a drinking water well or one or more plant or animal receptors. As designers of engineered facilities, we need to demonstrate to society how environmental quality objectives at these destinations will be met.

The other problem that we often deal with is remediation. This situation occurs where a destination has already been polluted, or is at risk of being polluted, and the engineering of retrospective containment, attenuation or clean-up action is required.

2. GROUPING OF THE 7th ANZ CONFERENCE GEOENVIRONMENTAL PAPERS

It is interesting to note that the papers submitted for this 7th ANZ Conference fall into three distinct categories.

The papers in the first category fall squarely into what might be termed "conventional geotechnical engineering with some interesting twists." These papers essentially discuss some of the research and engineering involved with converting land disturbed by mining activities into land which can be used safely for other purposes. They are different from the other papers in that they essentially deal with the physical condition of the land, albeit, land which has been disturbed by man in such a manner that prediction of the future stability of that land is made difficult.

The second group of papers fall squarely within the "source-pathway-destination" category, and most deal almost exclusively with the "pathway" question. They consider the engineering of containment systems (although a reality, it may be better to call these "leakage reduction" systems), and they give insight into how chemical concentrations can be calculated at a destination.

Thirdly, two companion papers deal with a specific groundwater remediation problem, although, once again, the transport and fate of chemical solutions under ground is a primary concern.

3. PAPERS DEALING WITH THE REUSE OF MINE AFFECTED LAND

3.1 The Role of Geomechanics in Mine Site Rehabilitation

This paper advocates the important role of geo-mechanics in the field of mine site rehabilitation rather than focusing of all of the efforts towards final agricultural land use. It deals with "traditional" geotechnical engineering and in particular, the physical properties of mine wastes (overburden, waste rock and tailings) and how to assess their long-term behaviour in terms of stability and settlement. It makes some interesting geotechnical points such as the difference between the "angle of repose" of dumped rock and its "angle of internal friction" and the fact that angles of internal friction as high as 45° to 55° at low stresses, probably apply.

The problems of crust development on tailings and the stability of tailings dam covers are also dealt with.

3.2 Physical and Numerical Modelling of Combined Sedimentation/Consolidation of Coal Tailings

In this paper, prediction of the properties of coal tailings subject to deposition in slurry form is investigated using laboratory experiments using tailings and tailings water from the New Hope Colliery. In addition, some computer models are developed to take into account the two phases of density gain in the tailings: namely settling and consolidation under self weight. The approach taken is empirical, but one which has been found to yield reasonable results for many instances in geotechnical engineering: namely using mathematical models which can predict laboratory behaviour of soils to a reasonable degree, then extrapolating with such models to the field situation.

3.3 A Field Study of Evaporation and Shrinkage of Slurried Mine Waste

In this paper, monitoring is undertaken in the field to assess the behaviour of mine waste (in this case, predominantly koalinitic "slimes" from the mineral sands industry). By measuring field parameters including shear strength, moisture content evaporation, and volume change, it was demonstrated that shrinkage cracks which form in such materials provide for significant additional drying of the mine slimes, possibly by as much as 30% in the upper layers.

3.4 Mine Fires in Abandoned Shallow Underground Coal Workings, Newcastle Coal Field, NSW

In this paper, the problem of long duration underground fires in closed, shallow coal mines above the water table are outlined. These fires result in sterilisation of large areas of land due to subsidence, surface fissuring and cratering as well as emission of toxic and explosive gases. Some interesting models of underground coal combustion are promulgated focusing on the availability of air for the combustion process and advection currents created by the dip of the workings and exhaust vents. Special measures incorporated in the newly completed Swansea Bends Deviation of the Pacific Highway where it crosses some old workings of the

Wallarah seam are outlined. That paper highlights the fact that when dealing with the uncertainties of subsurface conditions, engineering invariably has challenges. When such conditions have been altered by large scale ground failures and movement combined with the dynamic element of a fire which could result in further movement, there are particular challenges for the geotechnical engineer.

4. MODELLING THE "PATHWAY" IN THE "SOURCE–PATHWAY–DESTINATION" PROBLEM

Eight of the papers fall into this category. They deal with natural and man-made soil liners which are designed to reduce the release of contaminants, and they deal with the influence of natural geological materials on contaminant transport. In addition, some of the papers deal with the modelling of contaminant transport using some different approaches.

4.1 Preliminary Results on Soil Permeability and Physical Characteristics of Feedlot Pens

This is an interesting paper which relates to the beef cattle feedlot industry and deals with the in-situ permeability of feedlot pen surfaces. The manure left on the pens is a potential source of groundwater pollution from salts and nutrients. The study is not yet complete, but involves some purpose built feedlot pens, the surfaces of which were treated in different ways. Index test and permeability tests were carried out on the soils and mixtures of soil and manure from the base of the pens with conclusions drawn as to the degree of protection of groundwater afforded by these different cell treatments. It is interesting to note that reliance is placed on what is known as an "interface layer" which comprises of layer compact manure of low permeability on the original pen surface. It is an interesting re-use of a waste product to form an engineering barrier, although from the perspective of the landfill engineer, there would seem to be a lack of quality control involved. It is also interesting to note that only permeability was considered as the parameter which governs the rate of release of salt and nutrients into the subsurface. A later paper discussed in Section 4.2, dispels the notion that permeability is the governing soil property with regard to the release of contaminants through low permeability clay liners. This factor may warrant attention in the engineering of feedlot pens.

4.2 Determination of Key Parameters in Landfill Liner Design

This paper deals with some interesting experiments undertaken at the University of Newcastle relating to the migration of fluoride in solution through compacted clay soils. One figure shows the relationship between the absorption of fluoride from solution onto free clay particles in batch tests, as a function of the pH of the original solution. It demonstrates the importance of geochemistry which geotechnical engineers need to demonstrate some appreciation of, when trying to quantify these "pathway" questions. This of course, is of particular relevance to municipal waste landfills where the leachate chemistry changes as a function of time. This provides an additional element of challenge to engineers attempting to predict the release of contaminants through a liner into the underlying soils and groundwater. In this paper, diffusion cell experiments were used to demonstrate the much faster diffusion of fluoride in solution through koalinitic clay then through bentonite clay.

4.3 Use of Atterberg Limits for the Compatibility Assessment of Soils for Waste Containment Liners

In this paper, a complex geochemical question is dealt with in a simple, empirical way by engineers and scientists. It has long been known to geotechnical engineers that when Atterberg Limit Tests on a clay soil are undertaken in distilled water as against saline water, that a higher liquid limit and lower plastic limit will be obtained in the distilled water. In the paper, similar affects were noted for leachate (which is generally relatively saline) as well as acetic acid and methanol. It is generally thought that Atterberg limits can be correlated to hydraulic conductivity, and in particular, the higher plasticity index, the lower the permeability. It was shown that in all cases, combining clay soil with contaminants reduced the liquid limit and increased the plastic limit and the plasticity index continually dropped with an increase in the concentration of chemicals. One of the things not considered in the paper was that for a soil in the field, its actual permeability and plasticity characteristics in-situ will be influenced by the chemistry of the natural water occurring in the soil pores as well as any compaction water used. For example, if one could conduct PI testing on clay using its natural water chemistry, then one may see plasticity indices somewhere between a laboratory sample where distilled water was used and those which are produced using sodium chloride solution.

4.4 Application of Biopolymer Technology in Silty Soil Matrices to Form Impervious Barriers

This paper, from the Department of Civil Engineering of the University of Southern California, deals with supplementing compacted clay liner materials by adding biopolymers such as xanthum gum or sodium alginate to the soil matrix. It also considers mixing slime-forming micro-organisms with the soil. Such additives to the soil have the potential to reduce the soil permeability and increase the shear strength of the soil. Permeability tests confirm that a natural soil from California, when mixed with biopolymers did in fact exhibit a permeability of 1 to 2 order magnitude lower than the same soil without the biopolymers added. The undrained shear strength of the soil/biopolymer mixtures was also found to be higher by up to 50%. The added benefit of such barriers is also that they are "biologically active" and have the potential to enhance the biodegradation of contaminants as they seep through the barrier. Further work is however, required to establish the long-term performance of such barriers prior to their full scale use by engineers.

4.5 Microbiological Assessment of Clay Soil Contaminated with MEK

This paper, undertaken by engineers and scientists from the University of Sydney examines the behaviour of MEK in natural koalinitic clay from an industrial liquid waste management site which operated for several decades in the western part of Sydney. In particular, an assessment was carried out using soil respiration and other tests to see whether MEK degrading bacteria existed in-situ and whether such activity could be enhanced by adding vermiculite and/or MEK as a carbon source to soil samples in the laboratory. At this particular facility, MEK has been shown to have migrated through some 6m of Londonderry "koalinitic" clay, then 5m of silty to gravelly clay into the water table which lies within the Rickabys' Creek gravel. Concentrations of between 50ppm and 250ppm of MEK have apparently been observed in a monitoring well. This is consistent with past batch tests by the same authors which showed that MEK was not absorbed to the Londonderry clay in the laboratory. As might be expected, microbial activity in clay from 6m depth was not detected. Addition of a bulking agent (in this case the vermiculite) as well as MEK to the clay in the laboratory increased microbial activity, but it is not known whether the stimulation resulted from biodegradation of the MEK.

4.6 Geotechnical Considerations in the Sighting of the Thailand Hazardous Waste Landfill

This paper explains the selection criteria used for hazardous waste disposal site in Thailand which involved an initial screening of 55 locations and then a site specific investigation. It is interesting to note that a prescriptive approach was used using a double composite landfill base liner for reasons of "the demands of modern environmental protective measures for hazardous waste landfills." The approach adopted appears to be to use what is generally regarded as a stringent liner system, monitor performance into the future and undertake groundwater remediation if contamination is detected escaping the system. An alternative approach might be to consider what would be an acceptable rate of release of small quantities of contamination over time, then engineer the liner to meet these objectives.

4.7 Analysis of Contaminant Transport in Unsaturated Soil

In this paper, vertical downward seepage of contaminants through an unsaturated soil is analysed using a one dimensional time stepping finite element program. It tackles the fact that the unsaturated permeability of soil is different to the saturated permeability and is also different at different moisture contents. It compares the steady state flow models of programs such as POLLUTE (used for landfill design in Australia and North America) with a finite element method and shows that quite different results are found. In particular, the finite element method predicted faster contaminant transport and higher concentrations of contaminants than POLLUTE. The model is relatively detailed and currently expensive to run but this, is currently being addressed by the researcher.

4.8 Numerical Modelling of Contaminant Transport Using Random Field

In this paper, researchers from the University of New South Wales are proposing a probabilistic approach to take account of the geological uncertainty involved in assigning hydraulic conductivity values to aquifers. It raises the interesting philosophical point as to whether sedimentary processes can be reasonably modelled using statistical methods. No results are given for the work as the project is just starting.

5. CLEANING UP THE PROBLEM

Two related papers fall into this category:

1) **In-situ Bioremediation of Nitrate Contamination in Groundwater - One Dimensional Study. Part 1, Model Development** and;

2) **In-situ Bioremediation of Nitrate Contamination in Groundwater - A One Dimensional Study. Part 2 - Experimental Validation.**

In these papers, the problem of nitrate contamination in groundwater being used for domestic water supplies is tackled. Specifically, the mechanisms of transport of nitrate in aquifers and biological reaction processes which result in denitrification are presented. As with some of the research mentioned above, the model is then applied to laboratory experiments successfully. The model and the experiments show that there is potential for in-situ bioremediation of nitrate contaminated groundwater by injection of a carbon source (ethanol). However, the paper also recognises the difficulties in moving a successful laboratory experiment to the field scale.

6. CONCLUDING REMARKS

Geotechnical engineers are, and will increasingly be involved in environmental engineering problems, particularly those involving soil and groundwater contamination. As demonstrated in the above papers, "containment" or "leakage reduction" systems are of particular interest to the geotechnical engineer, but these need to be designed with the long-term future in mind.

Opportunities currently exist for geotechnical engineers to be proactive in formulating and solving the "source-pathway-destination" problems in a positive way. For example, as shown on Figure 1, if the microbiologists can convince us that stabilisation of municipal waste is a predictable process with time, we can design landfill "leakage reduction" systems for a finite life. For non-degradable waste however, the consequences of a finite design life for our containment systems are much greater, as shown on Figure 2. In such cases we need to consider the future costs of "re-containment" or treatment of such wastes.

Whilst we have come a long way over the past decade, there will be an increasing role for geotechnical engineers if we can quantitatively relate our designs to environmental quality objectives. All the necessary tools are currently within our grasp or close to our fingertips.

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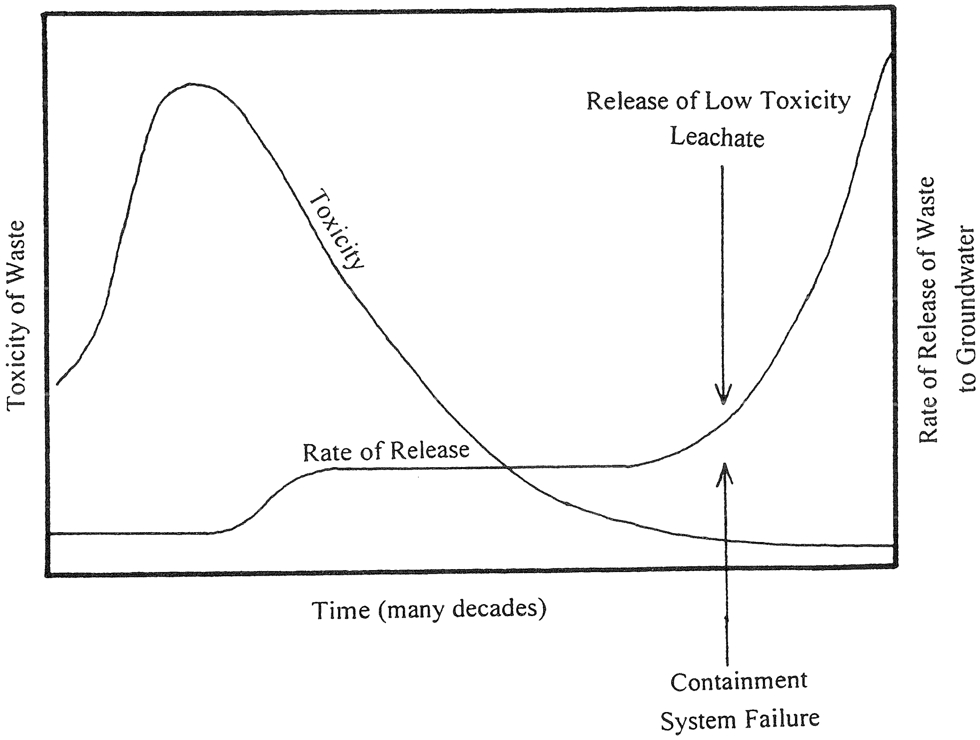

Figure 1. Time vs toxicity and rate of release for biodegradable waste.

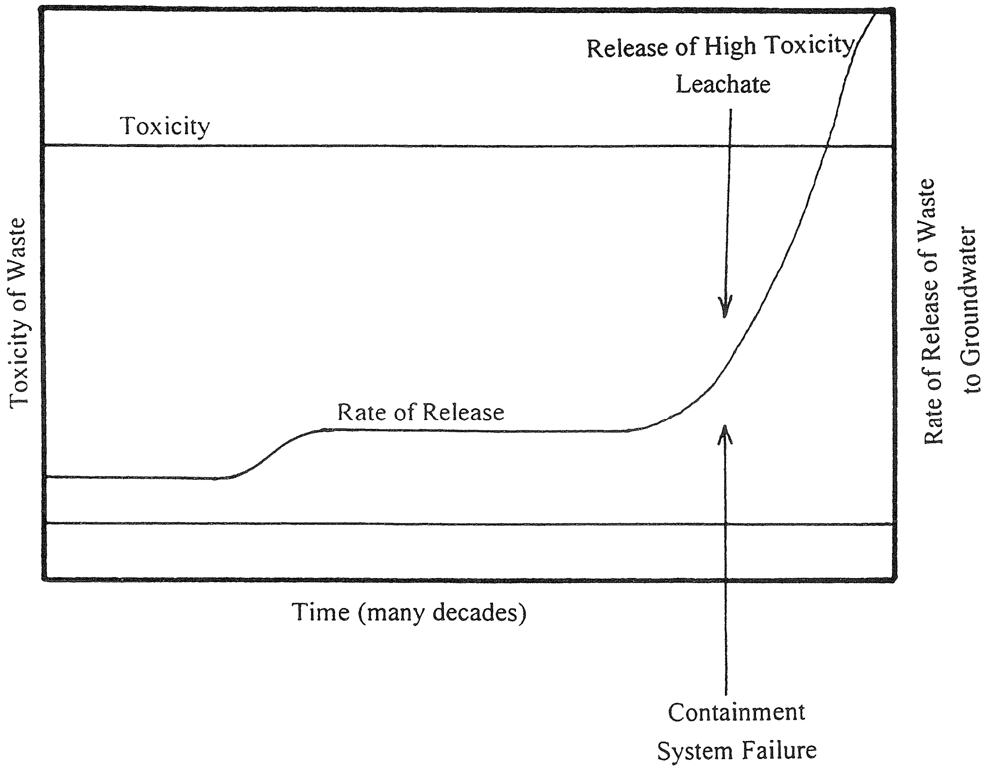

Figure 2. Time vs toxicity and rate of release for non-degradable waste.

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