Australian Geomechanics

News Journal of the Australian Geomechanics Society

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AUSTRALIAN GEOMECHANICS

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AUSTRALIAN GEOMECHANICS

News Journal of the Australian Geomechanics Society

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EDITOR'S NOTES

The Editorial Panel of Australian Geomechanics seeks contributions for future editions. The following comments are offered to assist would-be contributors.

Technical contributions can include any of the following:-

> Papers, not necessarily of standard or content required for acceptance in, say, the Transactions of the I.E.Aust. State groups might consider submitting selected addresses.
>
> Technical notes.
>
> Comments on papers published in Australian Geomechanics.
>
> Brief notes on "wrinkles" encountered in the practice of geotechnical engineering which contributor may be prepared to share with readers.
>
> Descriptions of geotechnical projects of special interest.
>
> Failures or "partial successes". Share your experiences with others.
>
> Contributions for the various regular columns and features.
>
> Letters to the Editorial Panel.

Australian Geomechanics is now being produced in electronic format using Pagemaker 4 on IBM compatible hardware. Contributions are therefore preferred in computer format.

The ideal is, of course, as a Pagemaker document however a variety of word-processing formats are acceptable. Wordperfect to version 5.1, Wordstar and Multimate can all be accepted. Text submitted as an ASCII file is also acceptable as are documents generated on Macintosh hardware. Please specify with your submission the format used to generate the file and include a hard copy. If the submission includes figures or photographs these may be incorporated directly into Pagemaker documents submitted. If submission is in word-processing format please submit camera ready copies of all figures and photographs.

Contributors may still present camera ready material which should be either A4 size if prepared on a laser printer or A3 for lesser quality of print. The following guidelines will assist with maintaining some uniformity of style and production (applies in the main to production A3 documents produced on other than laser printers):-

Text: The material should be submitted in typed form and preferably in the following format:

- o Character quality - double density letter quality.
- o Character size - 12 pts (10 pts on A4)
- o Column width - 110mm (85mm on A4)
- o Line spacing - single
- o Paragraph spacing - double
- o Main headings - numbered 1 to n, 10 cpi
- o Formulae - typed or clearly hand written
- o Lines per page - 55

Diagrams and tables: These should be sharp black on white and of the correct size for incorporation into finished document (ie 100mm wide for single column or 220mm wide for double column). Original ink drawings should be submitted if possible and can be returned if required.

Photographs: These should preferably be good contrast black and white gloss prints and of the correct size for incorporation.

Position: Please ensure that all such items are clearly marked to indicate position in paper.

Authors will remain responsible for the integrity of their material and for permission to publish.

Contributors are reminded that the deadlines for submission of material are 1 May for the June edition and 1 Nov for the December edition. Contributions should be forwarded to the Editorial Panel, Australian Geomechanics, c/- Department of Civil Engineering, Monash University, CLAYTON, VICTORIA 3168. Telephone (03)565 4982 or facsimile (03) 565 4944.

LIBRARY FACILITIES

All publications received by the Society are soon to be transferred to IEAust National Headquarters in Canberra. State Secretaries are to hold a full listing of items held. Enquiries regarding access to this library should be addressed to Peter May.

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SUPPORTING MEMBERS' PROFILES

As announced in the last issue of Australian Geomechanics, we are intending to publish profiles of Supporting Members of the Australian Geomechanics Society. These will be published on an 'as received' basis and we reserve our editorial rights to limit extreme self aggrandisement! So, if you would like to see your organisation's profile published here, send the details to the Editorial Panel (after checking that you have paid your Supporting Member's subscription!).

GFWA

GFWA are specialist geotechnical and foundation contractors and engineers serving all areas of construction in Western Australia including the mining, commercial, industrial, civil engineering, environmental control and domestic sectors. With the support of SIF Entreprise Bachy of France, GFWA is able to provide a comprehensive range of geotechnical techniques backed by extensive worldwide and unparalleled local experience. For the last twenty years, GFWA has worked all over Western Australia developing, designing and constructing economical engineering solutions.

Areas of expertise include foundation and lateral retention piles, all types of grouting, ground anchors, underpinning, vibroflotation, diaphragm walls, slurry trenches, guniting, soil nailing and dynamic consolidation. In addition, GFWA operates a site investigation service with an Electric Friction Cone Penetrometer truck, a variety of drilling rigs and equipment capable of recovering bulk samples.

For more information and technical advice, contact (09) 410 2311 (phone) and (09) 410 1297 (fax). Mel Birkinshaw, Simon Breen and Martin Fielder will be pleased to help you with your enquiry.

HOLLINGSWORTH DAMES & MOORE

Hollingsworth Dames & Moore, a division of Dames & Moore, provides a range of professional services in the specialist fields of geotechnical engineering, mining engineering and geomechanics, hazardous waste management, environmental and earth sciences, town and regional planning and hydrogeology. The firm operates principally throughout Queensland and Papua New Guinea with offices in Brisbane and Townsville, managed by Mike Marley, and offices in Cairns and Port Moresby managed by Geoff Byrne. Doug Ryan and Terry O'Keefe manage Earthtech (soils and materials) laboratories in Brisbane and Cairns.

The Geotechnical Engineering Group in Brisbane is managed by David Starr and the Mining Group by Doug Maconochie. The Hazardous Waste Management Group is headed by Rod Williams and the Hydrogeology Group by Yin Foong. The Terrain Analysis & Graphical Information Systems Group is headed by Gavin Renfrew. According to Peter Hollingsworth, Senior Consultant in the Brisbane Office, the range and quality of the in-house skills and depth of experience offered by Hollingsworth Dames & Moore in these specialist areas is aimed at providing clients with services which match engineering excellence with environmental responsibility.

WESTERN GEOTECHNICS

Western Geotechnics are entering their sixth year of operation in the soil, rock and construction material testing industry in Western Australia, and are looking to expand activities both technically and geographically. They will soon be offering an extended service in the area of geotechnical instrumentation. As well as being the WA agent for the Australian made range of GSA equipment, they will also be offering an instrumentation installation and monitoring service. They also offer an inclinometer data reduction service and a hire service for more expensive specialised equipment, such as inclinometer sondes. They are currently also installing a Casagrande style rock direct shear testing machine, which will also handle large size gravel samples. Other new equipment includes high pressure triaxial testing equipment and a Shimadzu universal tensile and compressive testing machine.

Western Geotechnics employ about 25 staff with Mr Ralph Newton as Managing Director and Mr Ron Hoffmann as Commercial Director. In addition to their laboratory in Rivervale, Perth, they opened a lab in Kalgoorlie two years ago and they have just opened other permanent labs in Mandurah and Port Hedland. The laboratories of Western Geotechnics can offer the full range of tests for soil, rock, aggregate, concrete and other building materials.

EDITORIAL

Since this is our last editorial before handing over the reins to the Victorian Group, we're inclined to be a little self indulgent and reflect briefly on some of the wins and losses of our spell on the Editorial Panel.

Almost inevitably, the last four issues of Australian Geomechanics have seen more than their fair share of news, views and papers from WA - however we must correct the impression that all geotechnical activity in WA revolves round the UWA centrifuge!! Not so, but the rotating editorship does give individual states the opportunity to do a bit of grandstanding, to push issues of particular concern and to throw the spotlight on geotechnical activity within their state. We would like to think that we've succeeded in all three areas.

From the outset, we attempted to standardise the journal format by computerising its production using desk top publishing software. This was not without its headaches, however when it was successful, we believe the result was very pleasing. The Journal was intended to be a half yearly publication however problems of work commitments, software incompatibilty and unfamiliarity, late copy and last but not least, poorly developed keyboard skills(two digit variety), all contributed to delay publication beyond the deadlines. For this we apologise and wish Victoria, 'the very best of luck'.

Thanks to Peter May, IEAust Canberra, advertising is now a regular feature in each issue and brings in important revenue, offsetting journal publishing costs.

Our intention to narrow the gap between geotechnical people in the mining and civil engineering areas has met with only limited success if measured in terms of published articles and papers of common interest. However on the local scene, the formation of a separate WA AGS Group in the gold mining town of Kalgoorlie is interpreted as a positive step towards bringing the two disciplines together. So too is the formation of the WA Centre for Geomechanics which will provide an important link between the resource industries and major research institutions in WA. Either initiative could in turn prove to be an important source of technical papers and talks for the wider geotechnical community.

This special issue is devoted almost entirely to Waste Management, fulfilling a commitment we made on first taking over the editorial hot seat. The very existence of this issue is a reflection of the growing concern within and outside the profession about the subject of waste and its safe disposal.

Too often in the past, the waste products of society have been poorly managed and have exerted a heavy toll on the environment. A growing awareness of the problem has lead in recent times to concepts of minimising and recycling waste. and where these are not possible, disposing of waste safely, i.e. in such a way that is within the capacity of the environment to absorb it. This is consistent with the idea of ecologically sustainable development which forms the subject of our guest editorial from WA-EPA's Browne-Cooper. His article is particularly timely as it follows closely on the heels of IEAust's release of its "Environmental Principles for Engineers". According to one of its authors, the main purpose of the Principles is to get across the importance of ethics in sustainable development and as such it largely complements the previously issued IEAust's Environmental Code of Practice, first published in 1987.

Whilst in recent years there has been a shift in emphasis of production strategies away from waste treatment to waste prevention, management of waste whether from the past, present or future, will continue to remain a significant problem facing society (sic engineers).

Of the various options for disposal of waste, sea outfalls - dumping at sea, incineration and disposal on land, all have their inherent problems for the environment and their critics. Even recently constructed sea outfalls whose designs are based ostensibly on studies of the assimilative capacity of the receiving environment, are showing signs of harmful impacts. Incineration is expensive , frequently produces unacceptable gas emissions and typically encounters its own brand of "nimby" type opposition. Disposal on land is no better off, carrying with it the potential for pollution of surface or groundwater resources and sterilising tracts of land.

In some cases however, disposal on land can be beneficial:

> The more benign waste such as digested sewage sludge can have value as a fertiliser in agricultural spreading however leaching of nutrients to water courses and soil contamination must be avoided.
>
> Red mud - bauxite residue - has been used to benefit to decrease the permeability of poor agricultural sandy soils making them better able to retain applications of fertilisers.

Other land disposal options of the more ecologically damaging waste rely on containment to prevent surface or groundwater contamination by leaching. This aspect of waste management is relatively familiar territory to the geotechnical profession and one which sees increasing application of the use of geomembranes. A review of their use in Australia is provided in the paper by Parker and Sadleir.

A companion paper entitled "Geosynthetic Containments in Environmental Protection" by Sadleir discusses the use of both membranes and geotextiles, alone or in conjunction with clay fill, as liners or caps, to provide landfill leachate containment.

Site investigations for proposed waste disposal sites and more particularly, for existing contaminated sites have their own characteristic problems. For contaminated sites, historical site records can give all important clues to likely contaminants and therefore which analytical tests to perform - you need to know what you are looking for to arrive at the correct test for finding it !! Again a prior knowledge of the site can be all important in knowing where to drill to locate any buried contamination.

These and other aspects of site investigation of contaminated land are addressed in "Auditing of Contaminated Land", a very useful paper by David Parker. Reasons for auditing are given together with key steps and pitfalls in the processes of field investigation, testing and assessing contaminated sites. Answers to 'What are acceptable levels of contamination for a particular site ??' are discussed and mention is made of Victoria's statutory audits. One wonders how long it will be before other states follow suit!!

Leachates from waste deposits contain chemicals which may adversely affect the sealing properties of clay liners or foundations. This type of chemical interaction was examined in the comprehensive investigations carried out for a landfill disposal site for aluminium smelter waste - the subject of an interesting paper by Sullivan and Knight. Fortunately in this particular case, batch tests identified good absorbtive capacity in the clay.

Gaining an understanding of the likely migration of contaminant plumes was achieved by Hensley and Savidou in experimental work using geotechnical centrifuge modelling. Results of the physical modelling according to their paper, compared favourably with numerical modelling and demonstrate yet again the versatility of the centrifuge in engineering investigations.

Mine tailings - the water borne fine waste product from mining activity deposited traditionally in characteristic and frequently unattractive waste dumps - has its own brand of environmental engineering problems:

> Traditional tailings disposal involving thickening and pumping the slurried tailings to dams/lagoons, presents problems for rehabilitation. The deposited tailings have initial high water content, correspondingly weak shear strength and occupy large areas of land which are susceptible to erosion.

A promising alternative disposal technique which overcomes many of these problems, involves mixing the tailings with 'coarse reject'. The combination of materials has improved engineering properties and behaviour, is easier to rehabilitate and has better future land use capabilities. The technique has been trialled successfully in the NSW coal mining industry and forms the subject of a paper by Williams.

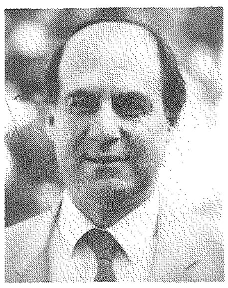
One of the key imponderables in the management of tailings disposal is the question of how quickly the waste material will consolidate and therefore improve in its properties. Fahey and Toh in their paper have developed a technique for examining and predicting consolidation behaviour of slurried tailings under various filling rates and boundary drainage conditions. For this they used a combination of numerical modelling based on large strain consolidation theory with input consolidation parameters obtained from geotechnical centrifuge modelling.

By its very nature, waste management frequently requires a multidisciplinary approach. This presents geotechnical engineers with a unique challenge in which they have to work with and have an understanding of many other disciplines. The latter can be achieved not only by training but by encouraging interdisciplinary debate in technical journals and in speciality conferences. One such conference is the forthcoming Conference on Geotechnical Management of Waste and Contamination due to be held in Sydney in March 1993.

The Editorial Panel strongly recommend anyone with an interest in waste management to take up the challenge and contribute to what we are sure will be a very successful conference.

Colin Bradbury, Trevor Osborne, Charles Waterton.

PETER BROWNE-COOPER —GUEST EDITOR



Peter Browne-Cooper is very well known in the environmental and waste management industries in Western Australia and indeed throughout Australia. In addition, he has come into public prominence here in the West through his previous position as Director of the Pollution Control division of the Environmental Protection Authority.

He graduated from the University of WA in 1964 with a B.Sc, majoring in physics and mathematics. He was with the 1965 Australian National Antarctic Research Expedition, specialising in geomagnetics and seismology. After a year with the Bureau of Mineral Research doing airborne geomagnetic surveys, he worked with the firm Geotechnics during the WA nickel boom.

Peter joined the Department of Environmental Protection (forerunner of the Department of Conservation and Environment) in March 1972 and, except for a secondment to the Australian Overseas Projects Corporation during which he worked in Jedda, Saudi Arabia, he has been with the EPA (and its antecedents) ever since.

He is currently A/Assistant Chief Executive Officer of the Environmental Protection Authority.

ECOLOGICALLY SUSTAINABLE DEVELOPMENT
IDEALISTIC MYTH OR A PRACTICAL APPROACH TO OUR FUTURE

Almost everyone - even the odd Geotechnical Engineer - has been exposed at some time recently to the term "ecologically sustainable development" (ESD): its the current environmental buzzword. A few of us may even have thought about what the term means. I suspect that very few indeed recognise the extent to which the concept can, and must, be applied to every aspect of human endeavour.

So what is ESD and why is it so important?

It is perhaps relatively easy to grasp the ESD concept in the context of forest or fishery management: one can see, at least theoretically, how the volume of timber removed can be limited to the growth volume each year, or the number of fish caught can be limited to the natural population growth. But is this true ecological sustainability - the action of removing trees or fish must change the ecological balance.

The practical implementation of ESD requires an understanding of two more "jargon" terms - *beneficial use and assimilative capacity*.

The *beneficial us* of a portion of the environment is the use assigned to it by society. The use of one piece of bush may be for protection of flora, another may be set aside for future residential development and another used for logging and regrowth; one estuary may be reserved as a shipping harbour, another for swimming, another for oyster culture; or there may be desire for a mixture of all these activities.

The ecology that we aim to sustain in those different areas of bush or those different estuaries may vary considerably:

- For the residential development we need to ensure that removal of vegetation will not produce flooding; perhaps that drainage will not adversely affect the beneficial use of the adjoining National Park; that air quality standards can be maintained; that groundwater uses are protected - very little of the pre-existing ecological diversity is necessary to sustain this beneficial use.

- For the flora protection reserve we need to ensure against introduced weeds and grazing animals; fire management may be necessary; flower picking may need to be controlled; a diverse range of insects and animals may need to be maintained for pollination; water quality and quantity in a wetland and depth to groundwater may be critical - a substantial amount, but perhaps not all, of the pre-existing ecological diversity may be necessary to sustain this beneficial use.

- For the logging area, removal of "weed" trees may be desirable to encourage commercial species; fire protection may be required; insect and animal pests may need control - if the only beneficial use to be sustained is timber production, some but not a lot, of the pre-existing ecological diversity may be necessary. If, on the other hand, multiple beneficial uses of timber production and wildlife conservation are desired, a far greater range of ecological diversity will be necessary.

The *assimilative capacity* of a portion of the environment is its ability to maintain a quality acceptable for the beneficial use or uses assigned to it or traditionally made of it, despite being subjected to some level of continuing interference.

Assimilative capacity is expressed as the quantity of a substance or intensity of an activity, alone or in combination with other substances or activities, which that portion of the environment can accept without jeopardising the beneficial use or uses assigned to it or traditionally made of it.

Looking again at the examples we have above:

- The residential area has a very large capacity to assimilate human trespass; being a low lying area with no wind it may have a very low capacity to assimilate smoke from domestic fires; the capacity to assimilate lawn fertiliser may be high if groundwater will only be used for garden irrigation but if there is a groundwater connection to wetlands in the adjacent National Park this beneficial use will dictate a lower assimilative capacity in order to avoid wetland damage.

- The flora reserve may be able to assimilate some human trespass, perhaps along designated tracks; smoke may not be problem but the plants may be highly susceptible to hydrogen fluoride for which the assimilative capacity will be virtually zero; a slightly elevated level of nutrients in the groundwater may be an asset but too much will kill the plants.

- The logging area may tolerate a quite high level of human trespass in the area of mature trees but seedling areas may have a very low assimilative capacity; smoke and some other air contaminants may only need to be controlled to levels appropriate to protect forest workers and casual visitors; quite high levels of nutrients in the groundwater might be able to be tolerated.

So different beneficial uses require different environmental management for their maintenance and may imply very different assimilative capacities. it follows that pollution or degradation of the environment only occurs when its assimilative capacity for the specified beneficial use is exceeded; conversely if the stresses placed on the environment are kept within its assimilative capacity they can continue indefinitely - ie we have ecological sustainability.

These concepts can be applied to virtually everything we propose to do - opening up land for housing or agriculture, building a factory, establishing a mine, disposing of wastes, creating a National Park, fishing for rock lobsters etc. We can test the sustainability of our proposal by following these steps:

1. Determine the present and likely future beneficial uses of, and surrounding, the site of the proposal;

2. Determine that environmental characteristics, which are likely to be impacted by some aspect of the proposal, are necessary to maintain those beneficial uses;

3. Determine for each of those aspects, the assimilative capacity in relation to the most sensitive beneficial use;

4. Measure the pre-existing load of each of those aspects;

5. Add the proposed load to the pre-existing load and compare the total to the assimilative capacity.

All this may look like an environmental consultant's dream come true - the trick is to make sure investigations are only done to the level of detail necessary to demonstrate that our proposal meets the requirements. If we want to dispose of large quantities of saline water to our tailings dam near the town water supply, we may need to do very detailed hydrogeological and engineering studies. If we are a long way from town in an area of known hypersaline groundwater very little investigation may be necessary.

If our proposal can be implemented and managed so that all the stresses placed on the environment are within its assimilative capacity our proposal will be *ecologically sustainable* and therefore:

- Our factory would be able to operate indefinitely without unacceptable environmental effect;

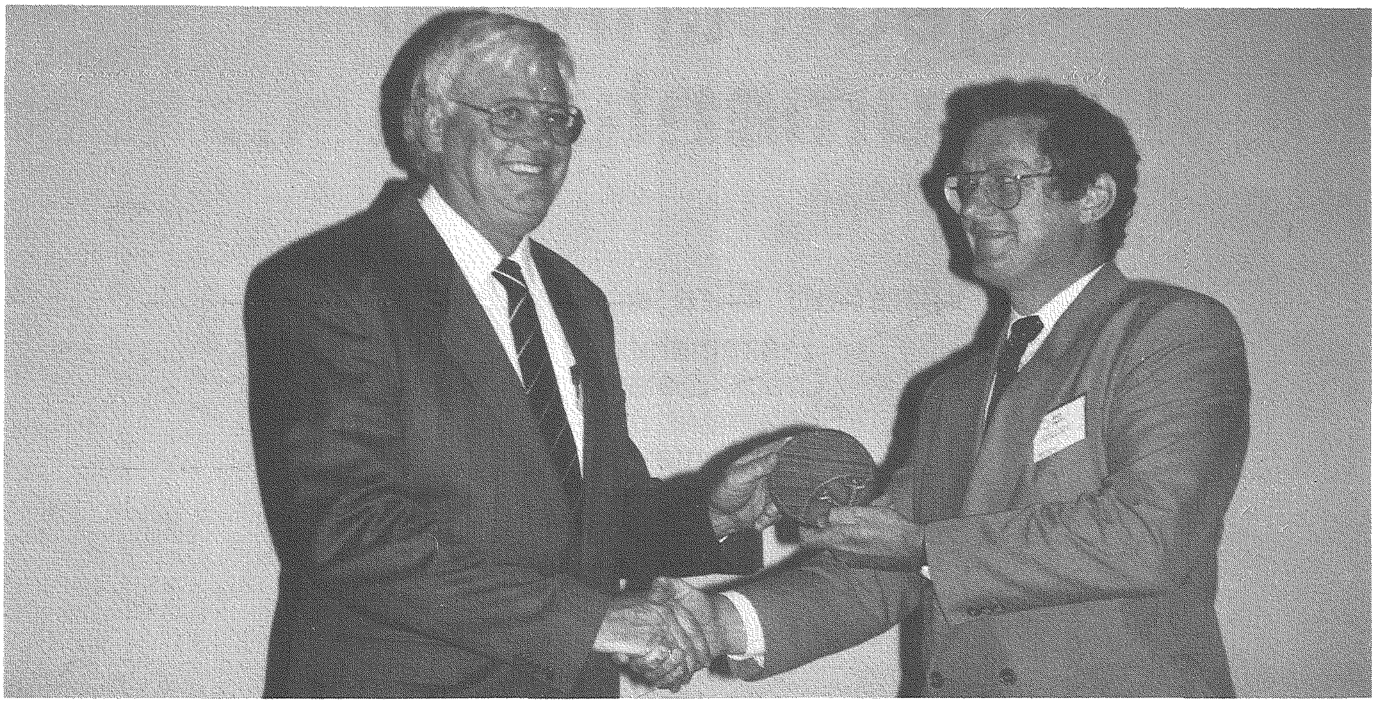
- We should be able to walk away from our mine and its tailings dam or the foundations of our offshore oil platform, confident that no unacceptable environmental hazard will arise in the future; and

- Our housing development will remain a pleasant place to live without adversely affecting the adjacent National Park which, in turn, should be able to continue to support its wildlife conservation and tourism functions indefinitely.

This is what ecologically sustainable development is all about - a sensible and essential approach to human activity.

Peter Browne-Cooper

1992 JOHN JAEGER MEDAL WINNER — Dr BRIAN RICHARDS



Dr Brian Richards receiving the John Jaeger Memorial Medal from AGS Chairman Max Ervin

The 1992 John Jaeger Medal winner is Dr Brian Richards. It was awarded to Dr Richards at a special ceremony at the 7th ANZ Geomechanics Conference in Christchurch, New Zealand in February 1992. Dr Richards then presented his paper "Modelling Interactive Load Deformation and Flow Processes in Soils" to the conference delegates.

Brian Richards was born in 1934 and obtained a First Class honours degree in Civil Engineering from the University of Adelaide in 1956. After a period with the Highways Department of SA, he joined the CSIRO Division of Geomechanics in Melbourne in 1959. Apart from a few changes in title and divisions, he has been with CSIRO ever since and has recently moved to Brisbane with the Division of Geomechanics.

During his 32 year stint with CSIRO, Brian Richards has developed an international reputation in the field of the physical behaviour of soils of the semi-arid to arid environment, and particularly unsaturated and expansive soils. His early work was pioneering research in a field in which very few workers at the time had made significant advances. This mainly fundamental research led to the development of new techniques for the definition, measurement and prediction of soil suction for geotechnical applications in the unsaturated soils of Australia.

Following on from this early work, he applied his knowledge and techniques to a wide range of applied problems, including road pavements in dry climates, foundations on expansive soils, retaining walls, slope stability in open cut mines, landslides in tropical areas, embankments constructed with expansive soils, compaction of agricultural soils, root penetration problems in compacted soils and, in recent times, water and contaminant transfer in rehabilitated mine sites. He is now considered a world authority in the use of unsaturated and expansive soils in agriculture and in civil, mining and environmental engineering.

His work and achievements clearly make Dr Brian Richards a very worthy and deserving winner of the 1992 John Jaeger Memorial Medal, which was instituted by the Australian Geomechanics Society in 1979 in memory of the late Professor John Jaeger. It is awarded every four years to coincide with the ANZ Conference. Jaeger was born in Sydney in 1907, graduating from the University of Sydney in Mathematics and Physics in 1928. After a period at Cambridge, he returned to Australia in 1935 to take a lectureship at the University of Tasmania where he subsequently became Professor of Applied Mathematics. In 1953 he moved to the Australian National University in Canberra as Professor of Geophysics. Although mathematics was probably Jaeger's main field of endeavour, he is well known for his work in Rock Mechanics, being a pioneer in the field. He wrote 6 books and published over 120 papers.

The John Jaeger Medal is awarded to an individual, or group of individuals, considered to have made a significant contribution to Australian geomechanics over recent years. The medal comprises a bronze casting, mounted on a piece of Wombeyan marble, this being the material with which Jaeger did much of his work.

PHYSICAL MODELLING OF CONTAMINANT TRANSPORT PROCESSES

P.J. HENSLEY* and C. SAVVIDOU+

1. INTRODUCTION

The objective of any modelling exercise is one of simulation and prediction. In the particular case of subsurface contaminant transport, modelling provides valuable information about the spread and growth of pollutant plumes, and the effectiveness of various containment and remedial action strategies. Modelling can thus offer much assistance in identifying the optimum course for environmentally sound waste management.

Various types of models are available. These include physical models, where a scaled model is tested in the laboratory or field; analogue models, where the process under examination is replaced by a process that behaves in a similar manner; and mathematical models, where the process is reduced to a set of governing equations, which are subsequently solved using either analytical or numerical methods.

This paper describes a physical modelling technique, namely centrifuge modelling, that has the potential to provide worthwhile assistance in the investigation of many contaminant transport processes.

1.1 Background

Prediction of the movement and accumulation of contaminants in groundwater flow systems is often carried out with the aid of theoretical models, that provide mathematical simulations of the problem under consideration. The results of any modelling exercise are wholly dependent upon both complete understanding of the fundamental processes involved, and accurate conceptual modelling of all relevant mechanisms.

In recent years, it has become apparent that a critical need exists for physical observations of pollutant behaviour in soils. Such observations are required both to validate existing mathematical transport models, and to aid us in developing improved conceptual models of fundamental transport processes.

Historically, controlled field experiments and laboratory column tests have provided the bulk of experimental data on pollutant behaviour in soils. Controlled field experiments have the advantage of modelling the total complexity of the full scale problem. However, these tests are costly, extremely difficult to perform and usually offer little direct control over boundary conditions. On the other hand, laboratory column experiments, which are generally inexpensive and relatively uncomplicated to perform, are often of limited value, due to their inability to model realistic boundary conditions.

Recently, researchers have come to recognise that a geotechnical centrifuge can provide a powerful experimental tool for investigation of many environmental engineering problems (Savvidou, 1988, Hensley and Schofield, 1991). A geotechnical centrifuge has the ability to model complex two and three dimensional problems, under repeatable and controlled boundary conditions.

The research presented in this paper investigated two environmental engineering problems, using the technique offered by geotechnical centrifuge modelling. The first problem concerned contaminant transport from a land based waste disposal site, and results from this investigation are compared with predictions from a theoretical transport code. The second problem concerned combined heat and contaminant transport from a buried waste source.

2. PRINCIPLE OF CENTRIFUGE MODELLING

The mechanical behaviour of a prototype soil mass under the earth's gravity g, can be replicated in a small scale model of $1/n$ experiencing a centrifugal force of ng, figure 1. If the product of depth times acceleration is the same in model and prototype, the stress distribution throughout the model will be identical with that throughout the prototype.

Centrifuge model tests therefore offer a means of carrying out small scale physical modelling of geotechnical problems, at stress levels similar to those experienced by the prototype.

Centrifuge modelling of environmental engineering problems is essential if stress gradients within the soil and/or gravitational forces influence the problem under investigation. Examples of problems where these factors may be important are given below.

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1) The movement of liquid pollutants in water bearing strata is heavily dependent upon soil permeability. The permeability of many compressible soils is a function of both the stress level and the stress history of the soil.

2) Physical transport due to gravitational forces will enter all waste transport problems involving convective heat transfer and/or interaction between fluids of different specific gravities.

3) Many pollutant transport problems involve flow, at some stage, in groundwater systems where gradients of total potential are governed by gravity.

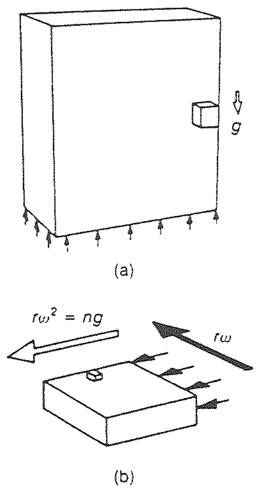

Figure 1: Principle of Centrifuge Modelling (from Schofield, 1980): (a) prototype; (b) model

2.1 Scaling Laws

The general scaling laws that govern the relationship between the model and its corresponding prototype, with respect to the problem of hazardous waste migration, have been derived by Bachmat (1967) and Hensley (1988) using inspectoral analysis, and by Laut (1975) and Arulanandan et. al. (1988) using dimensional analysis. The relevant laws are summarised below.

$$t_p = n^2 t_m \quad (1)$$

$$u_p = (1/n)\, u_m \quad (2)$$

$$c_p = c_m \quad (3)$$

where: n = scaling factor

m = model

p = prototype

u = pore fluid velocity (L/T)

t = time factor (T)

c = pollutant concentration (M/L^3)

The scaling laws were based upon assumptions that the transport of contaminant by dispersive processes would be identical in model and prototype, and that adsorption of contaminant at the fluid/particle interface would obey a rapid, linear equilibrium model. These assumptions may not be reasonable in many practical cases (Hensley and Schofield, 1991). However, a centrifuge model can always be regarded as an independent geotechnical event, producing data under repeatable and controlled laboratory conditions. Irrespective of the validity of the scaling laws, such data can therefore still be used to test and verify the mathematical modelling of transport processes.

Equation 1 states that events related to hazardous waste transport occur n^2 times faster in a centrifuge model than in the corresponding prototype. It is this feature which allows *accelerated* physical modelling of environmental engineering problems in a geotechnical centrifuge.

2.2 Verification of Scaling Laws

Verification of centrifuge scaling laws is usually carried out by performing 'modelling of models', where centrifuge models are tested at different scales and similitude between models is observed. Verification of the centrifuge scaling laws presented by Equations (1), (2) and (3), was carried out by Arulanandan et. al. (1988) at the University of California, Davis (figure 2).

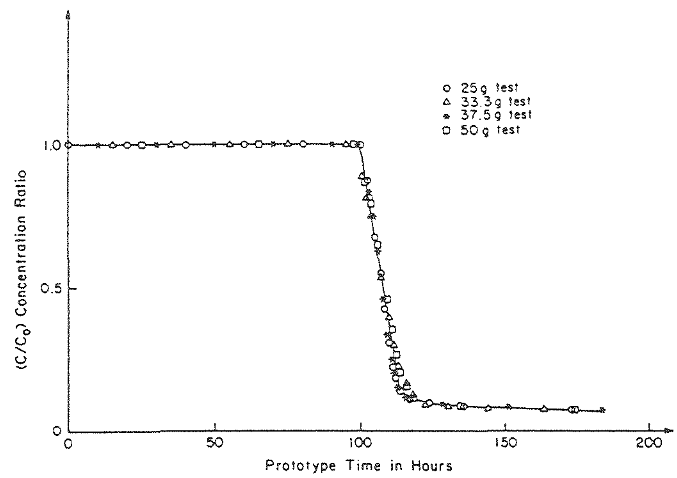

Figure 2: Verification of Scaling Laws by 'Modelling of Models' (from Arulanandan et. al., 1988)

Arulanandan et. al. concluded that the centrifuge scaling factors were correct provided that:

1. Hydrodynamic dispersion processes are identical in model and prototype.

2. Adsorption processes at the fluid-solid interface are described by rapid, linear, equilibrium laws.

3. MODELLING CONTAMINANT TRANSPORT FROM A LANDFILL SITE

The research described in this section of the Paper was conducted on the Balanced Arm Centrifuge at the University of Cambridge, England. The reader is referred to Schofield (1980) for a description of this facility.

The fundamental aim of the research was to investigate the technique of accelerated physical modelling of waste transport processes, offered by geotechnical centrifuge modelling. For this purpose, it was decided to model the migration of a single conservative pollutant species (sodium chloride) through a saturated soil deposit of finite depth.

The prototype problem chosen for the study concerned a 25 m wide, infinitely long trench of 3 m depth, sited in a 15 - 20 m deep soil deposit underlain by a permeable base stratum with horizontal groundwater flow, figure 3. Depletion of contaminant in the landfill with time was also incorporated in a number of the models.

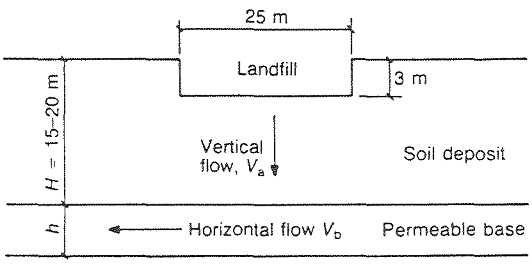

Figure 3: Prototype Problem

A standard sodium chloride solution (concentration Cl^-, 0.6 mol/dm^3) was used to represent the landfill contaminant.The principal geological deposit was formed from reconstituted 180 grade silica flour. The permeable base stratum in the model was constructed from Leighton Buzzard 25/52 sand.

A schematic representation of a typically instrumented centrifuge model is given in figure 4.

The progress of the salt-water contaminant as it moved through the soil sample was monitored by miniature four-electrode resistivity probes, that were designed and manufactured at the Cambridge University Engineering Department. These probes were also able to monitor the concentration of solution held within the landfill site. Druck miniature pore water pressure transducers were used to measure both equipotential heads within the soil body and soil surface water levels. Soil surface settlements were detected by Linear Variable

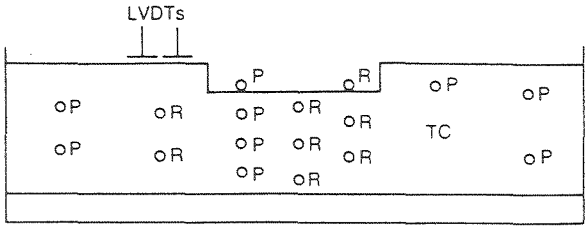

Figure 4: A Typically Instrumented Centrifuge Model: P, pore pressure transducer; R, resistivity probe; TC, thermocouple; LVDT, linear variable differential transformer

Differential Transformers (LVDTs), and the temperature within the soil body was recorded by an insulated buried nickel-chrome thermocouple.

Figure 5 illustrates the service arrangements for a typical centrifuge model. The advective seepage velocity through the silt layer, and the horizontal velocity in the permeable stratum beneath the silt, were controlled by water levels within standpipes connected to the model. Alteration of standpipe overflow heights allowed for the variation of model seepage velocities between tests.

Each centrifuge test followed the same general procedure. Initially the centrifuge was started, and the speed was increased in stages to 100 gravities (100*g*). The flow pattern within the model was then established using a 'fresh' water supply to the landfill[1]. After approximately 2 hours, when the resistivity probe and pore pressure readings indicated steady state conditions within the model, the fresh water was removed from the landfill and replaced by a sodium chloride solution while the centrifuge was still in flight. For the remaining duration of the test, the landfill was supplied with either a standard sodium chloride solution, representing a constant concentration of pollutant within the landfill, or fresh water, representing a depletion of landfill pollutant concentration with time. Signals from all instrumentation were monitored throughout each test, and various events of each test were recorded by Polaroid photography.

At the end of each test, the centrifuge was stopped and a site investigation of the model was undertaken. The package was then removed from the arm of the centrifuge, and radiographed to reveal the exact location of the buried instrumentation..

[1] Mains tap water was used to simulate a 'fresh' water supply.

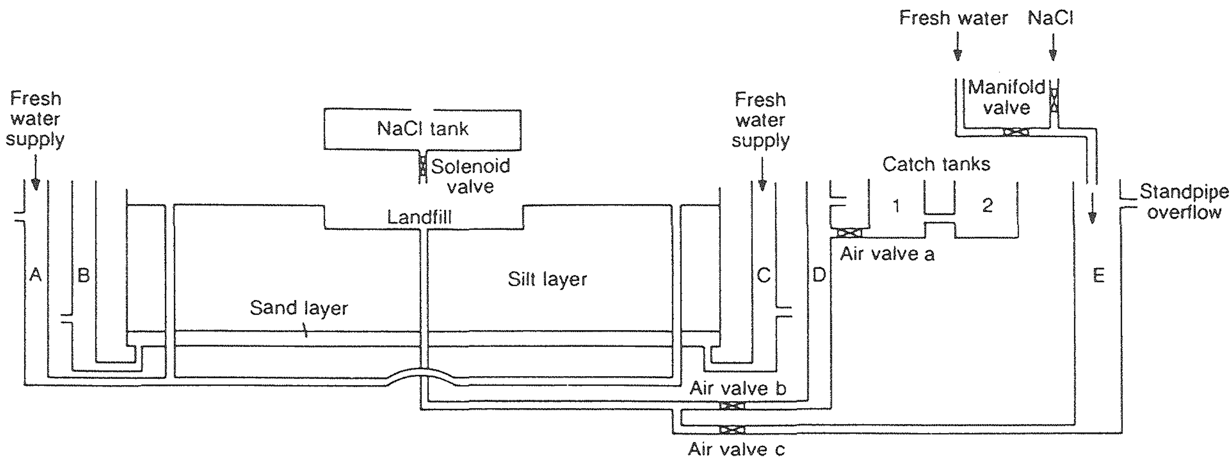

Figure 5: Schematic Diagram of Centrifuge Model

3.1 Comparison of Centrifuge Data and Theoretical Predictions

A total of seven centrifuge model tests were undertaken to study the transport of pollutants in the soil surrounding a land based waste disposal site. The model tests encompassed a number of groundwater seepage velocities and a variety of landfill boundary conditions. Results from the centrifuge tests were compared with theoretical predictions from two commercially available computer transport codes, POLLUTE and MIGRATE (Rowe and Booker 1983, 1985a and 1985b), and with analyses developed during the course of the research (Hensley, 1989, Hensley and Schofield, 1990).

The POLLUTE code uses semi-analytical techniques to solve a one-dimensional contaminant transport equation in a layered soil deposit of finite depth. The problem description for this analysis is illustrated by figure 6.

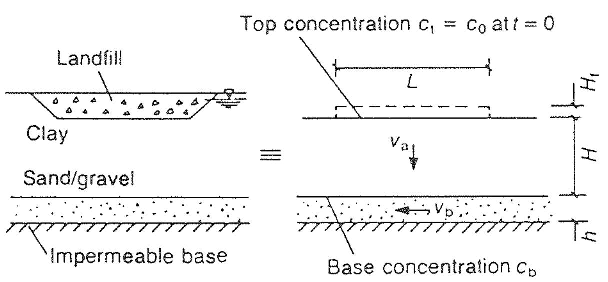

Figure 6: Problem Description for POLLUTE (from Rowe and Booker, 1985a)

In the following, a comparison of experimental data and predictions by POLLUTE is given for the fifth centrifuge test in the series, Test PJH5. The results are presented in prototype time and normalised with respect to c_s, the concentration of the model pollutant. In all figures, the theoretical data are represented by discrete points. The reader is referred to Hensley and Schofield (1991) and Hensley (1992) for a comparison of further centrifuge tests with POLLUTE and alternative theoretical analyses.

The steady state groundwater flow pattern established within model PJH5 during centrifuge flight is shown in figure 7. This seepage flow net was generated by a two-dimensional finite element program for groundwater flow, that was developed during the course of the research (Hensley, 1989).

Figure 7 clearly illustrates the two-dimensional nature of the seepage pattern established within each centrifuge model. However, this figure also demonstrates an approximately one-dimensional seepage flow pattern in the area of soil directly below each landfill site. It is therefore reasonable to expect theoretical predictions from POLLUTE to provide an agreeable estimate of the concentration rises recorded during test PJH5, at all measurement points located in the central section of the model.

Centrifuge test PJH5 modelled a landfill sited in a 14.8 m deep silt deposit, underlain by a sand deposit of 2.5 m depth. An apparent (Darcy) vertical flow velocity of 0.965 m/year was set through the soil beneath the landfill site[2], and an apparent horizontal flow velocity of 230.21 m/year was imposed along the base aquifer.

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[2] The apparent seepage velocity used in POLLUTE corresponded to the component of velocity induced by forced convection. Because the density of the model pollutant was greater than the density of the interstitial fluid, free convection would have been responsible for a component of the total convection through the model. However, the actual percentage contribution made by free convection was negligible for the conditions of test PJH5.

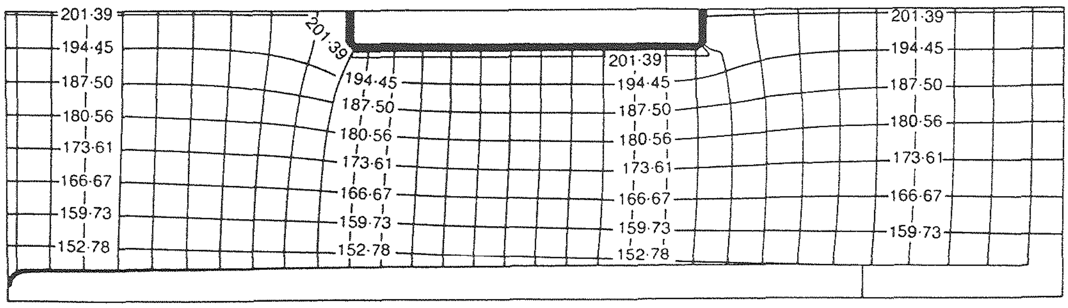

Figure 7: Steady State Seepage Net for Centrifuge Test PJH5

A comparison between theoretical and experimental data for test PJH5 is given in figure 8: Prototype dimensions and the position of appropriate measurement points are also given in this figure. The parameters required as input by the POLLUTE program were obtained from site investigation of the centrifuge model, and from independent laboratory tests.

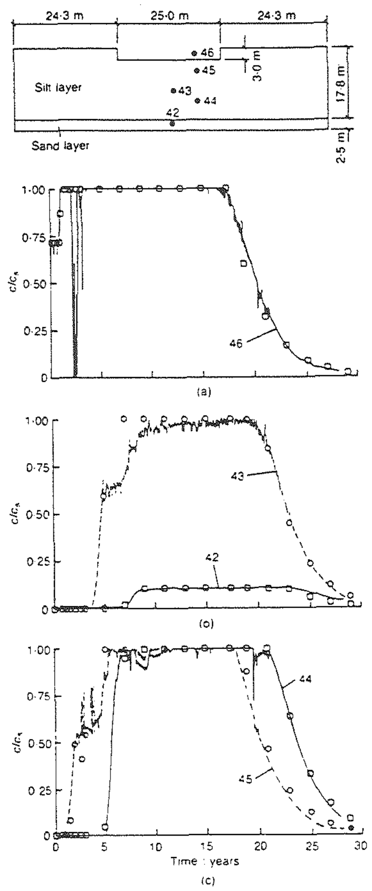

Figure 8: Measured and Predicted Concentration Changes During Test PJH5; theoretical data are represented by discrete points; (a) at probe 46 (landfill site); (b) at probes 42 (sand layer) and 43 (silt layer); (c) at probes 44 and 45 (silt layer); insert, transducer locations and prototype dimensions.

Figure 8a illustrates the concentration profile in the landfill site throughout the duration of the migration event. The landfill concentration was maintained at the maximum value, c_s, for the first 17.5 years of the migration event. Thereafter the landfill concentration was allowed to diminish with time.

Figures 8b and 8c compare experimental and theoretical data at all measurement points located directly beneath the landfill site. It is apparent from these figures, that excellent agreement was obtained between observed and predicted data at all points. Both the increase in concentration at all points during the initial stages of the test, and the decrease in concentration at these points during the latter stages of the test (when pollutant concentrations in the landfill were allowed to reduce), were well modelled by the program POLLUTE.

The magnitude of peak concentration at the probe positioned in the aquifer, probe 42, was only 10% of the maximum landfill concentration, c_s. This indicates that both the horizontal influx of fresh water along the base aquifer, and the high horizontal seepage velocity within this stratum, combined to reduce pollutant concentrations in this layer of the model.

3.2 Summary

The research presented in this section of the Paper was undertaken to investigate the technique of accelerated physical modelling of groundwater flow processes, offered by geotechnical centrifuge modelling. The centrifuge tests performed during the course of this research were the first tests of this nature to model a realistic prototype configuration on a large capacity centrifuge. These tests were shown to provide valuable data on the migration of a conservative pollutant species through the soil beneath an engineered trench site, for a wide variety of initial and boundary conditions. Prototype times of up to 30 years were modelled during the test series. Long term in-situ experiments of this nature would have been costly and extremely expensive to perform, and may have provided little direct control over boundary conditions.

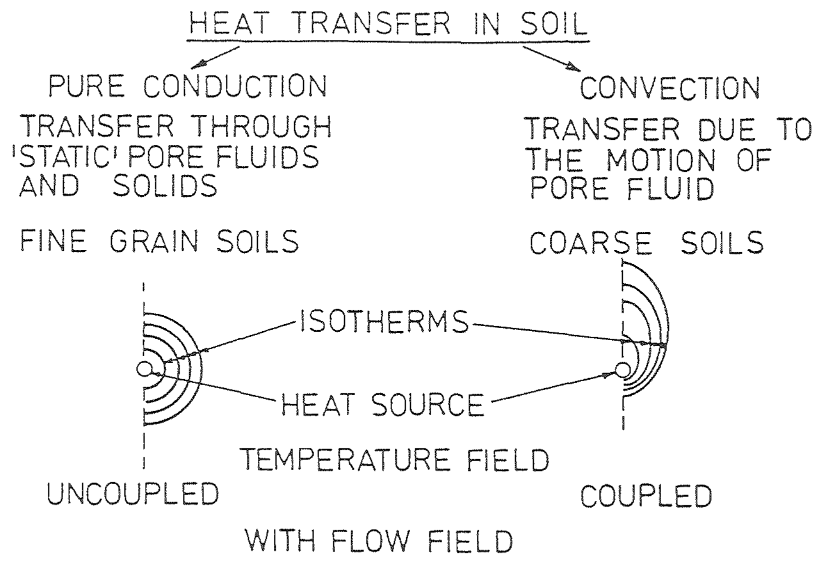

Figure 9: Heat Transfer in Soil

The centrifuge test results were compared with data from a commercially available contaminant transport code. These comparisons served to illustrate the enormous potential of a geotechnical centrifuge, in providing good quality experimental data for the verification of mathematical transport models.

4. MODELLING COUPLED HEAT AND CONTAMINANT TRANSPORT

The problem of coupled heat and contaminant transport in soils is of importance in environmental engineering problems relating to the storage and disposal of heat generating high level radioactive wastes, high temperature waste discharges from power plants and industrial processing plants, and transport processes occurring in geothermal reservoirs and thermal storage aquifers.

Heat transfer through soil may take place by pure conduction alone, in which case heat is transported through the 'static' pore fluid and through the soil particles themselves, or it can take place by convection, in which case heat transport is due to the physical motion of the pore fluid itself (Savvidou 1988), figure 9.

The transition from conductive to predominantly convective mass transfer in soil is characterised by the effective dimensionless Rayleigh Number, R_a, which symbolises the balance between the driving buoyancy force induced by convective motion, and the resistive processes of viscosity and diffusivity (Hensley and Savvidou, 1992). For centrifuge modelling techniques

$$R_{a_m} = R_{a_p} \qquad (4)$$

Equation 4 thus indicates that similarity will be achieved between a reduced scale centrifuge model and the prototype, with respect to the mechanism of combined heat and contaminant transport.

Convective transport in soil induces fluid motion in the region surrounding the waste source. Because advection is an important mechanism in many contaminant transport problems, the presence of a convective cell may well dominate the growth and spread of a pollutant plume.

The centrifuge tests described in the following, were designed to investigate mechanisms of combined heat and contaminant transport in saturated soil. These tests were conducted on the centrifuge facility at the University of Western Australia. The reader is referred to Randolph et al. (1991) for a description of this facility.

4.1 Physical Modelling and Experimental Results

The model form that was used during the study is illustrated by figure 10.

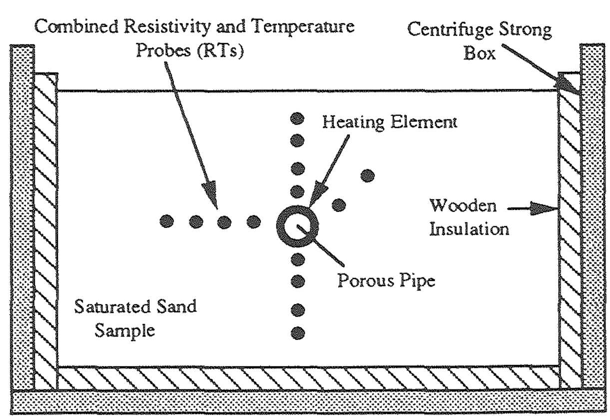

Figure 10: Model Configuration

The models were constructed from saturated silica sand, and enclosed in a rectangular centrifuge strong box. A standard sodium chloride solution (concentration Cl^-, 0.2 mol/dm^3) was introduced into each model during centrifuge flight, along a buried, horizontal porous pipe. A small positive hydraulic gradient was maintained between the pipe and the upper and lower surfaces of the model. A heating element surrounding the porous pipe allowed the temperature of the sodium chloride leaving the pipe to be raised by up to 40°C above the ambient temperature.

During each test, temperature and concentration rises in the soil surrounding the pipe were monitored by miniature combined resistivity and temperature probes. These probes comprised of two Platinum-Rubidium (Pt-Rb) wires buried in a small cylindrical core of porous ceramic material. Temperatures at the electrodes were measured by Nickel-Chrome Thermocouples, that were bonded to the base of the probes. The grain size of the ceramic material surrounding the electrodes closely matched the average particle diameter of the modelling materials used. It is therefore believed that the probes offered minimal disruption to the measured pattern of contaminant transport.

A series of eight tests was carried out to investigate coupled heat and contaminant transport in soil. These tests investigated the influence of both particle size and buoyancy effects on the transport mechanisms. The reader is referred to Hensley and Savvidou (1992) for a full discussion on the test series.

In order to illustrate the influence of buoyancy effects on heat transport mechanisms, two tests were conducted in the same sand at different *g*-levels. Results from the two tests are shown in figure 11, which presents reorded temperature rises (delta T) in the soil directly above and below the buried pipe.

Figure 11 clearly demonstrates different heat transport mechanisms at 100*g* and at 1*g*.

At 100*g*, the sensors positioned above the buried pipe registered a very sudden increase in temperature, suggesting rapid heat transport through the motion of pore fluid. However, at 1*g* the sensors above the pipe registered a slower increase in temperature, suggesting more gradual heat transport through static pore fluid and solids.

In addition, the temperature field surrounding the buried source at 100g was indicative of the 'flame shaped' isotherms associated with convective heat transfer (refer to figure 9), whereas an approximately symmetrical pattern of isotherms was observed around the source at 1g, thus intimating the presence of conductive heat transport.

The influence of convective heat transfer on contaminant transport was investigated by conducting two experiments in coarse sand at 100*g*. In the first experiment, the salt water contaminant was allowed to flow from the buried porous pipe at ambient temperature. In the second experiment, the heating element surrounding the pipe was raised to a temperature of approximately 60°C. Results from these two experiments are given in figure 12, which presents recorded concentration rises in the soil directly above and below the buried pipe.

The data shown in figure 12 explicitly illustrate the influence of convective heat transfer on contaminant transport. In the absence of heat transfer, the (dense) contaminant merely migrated to the lower region of the saturated sand model. However, in the presence of heat transfer, the contaminant was transported into both the upper and lower regions of the model.

4.2 Summary

The research presented in this section of the Paper demonstrated distinct differences in the heat transfer mechanism at 1*g* and 100*g*, and confirmed that thermally induced seepage velocities can have a major effect on the transport of contaminants in soil.

The research also served to illustrate the enormous potential of a geotechnical centrifuge, as a research tool for investigation into fundamental transport mechanisms.

5. CONCLUSIONS

This paper introduced geotechnical centrifuge modelling as an experimental method for modelling subsurface contaminant transport.

Centrifuge modelling is a technique that allows accelerated physical modelling of many contaminant transport problems, under well controlled and repeatable laboratory conditions. The usefulness of the centrifuge as a modelling tool was demonstrated by the value of data presented from two test series.

The first test series, which investigated solute migration from a land based waste disposal site, was shown to generate worthwhile data for comparison with existing transport codes.

The second test series provided valuable insight into fundamental mechanisms of combined heat and contaminant transport.

Clearly, a geotechnical centrifuge offers a very powerful testing tool for the physical investigation of many environmental engineering problems.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the excellent technical support received during the course of the research presented in this paper.

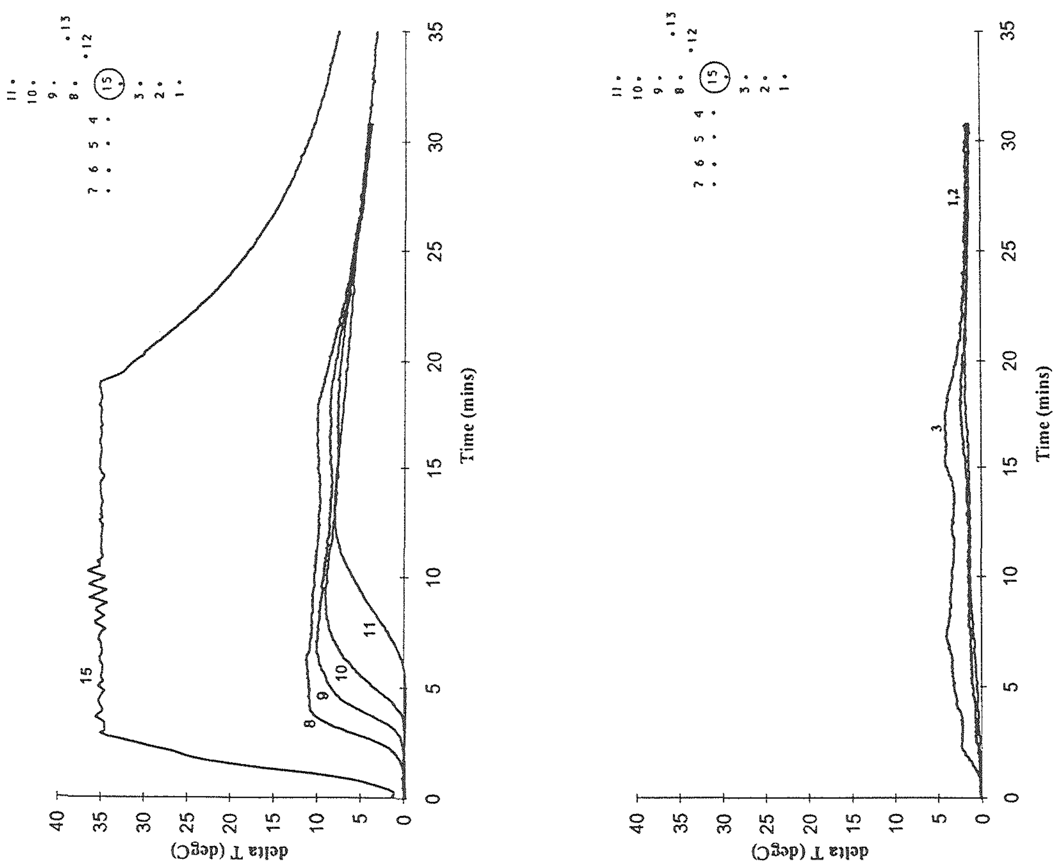

Figure 11a: Variation of Temperature Surrounding Heater with Time at 100*g*

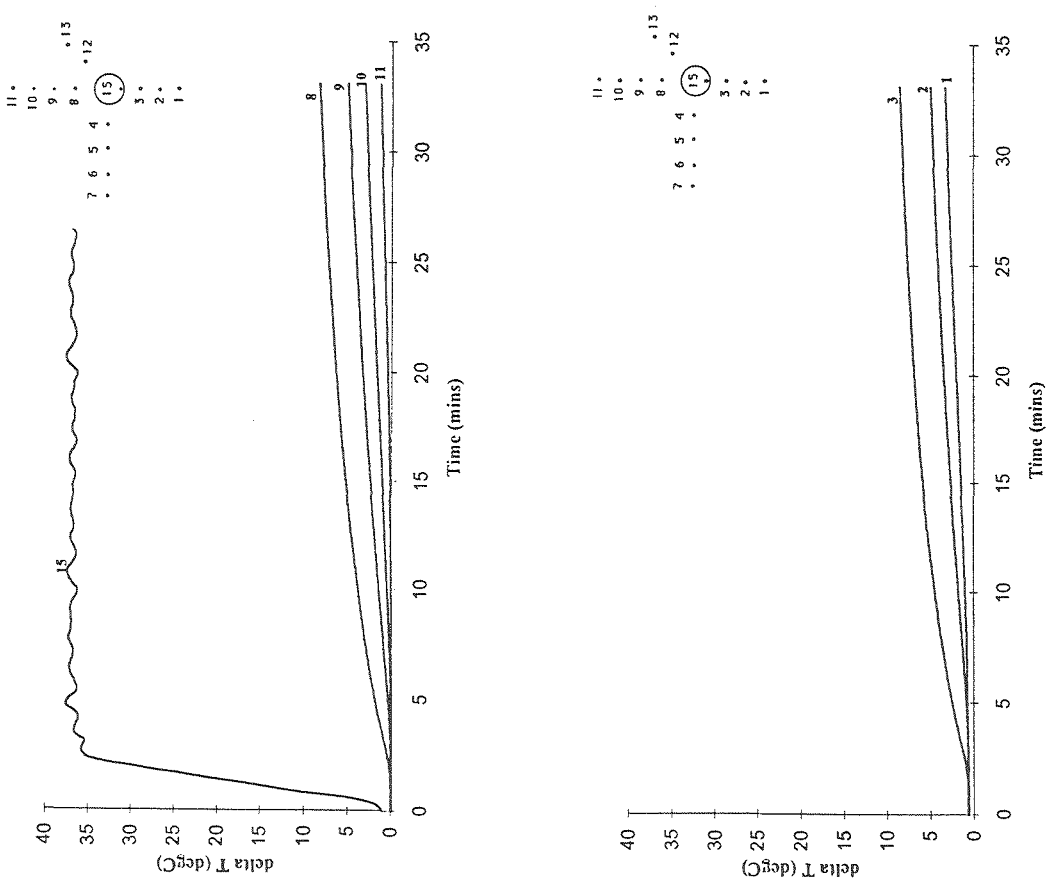

Figure 11b: Variation of Temperature Surrounding Heater with Time at 1*g*

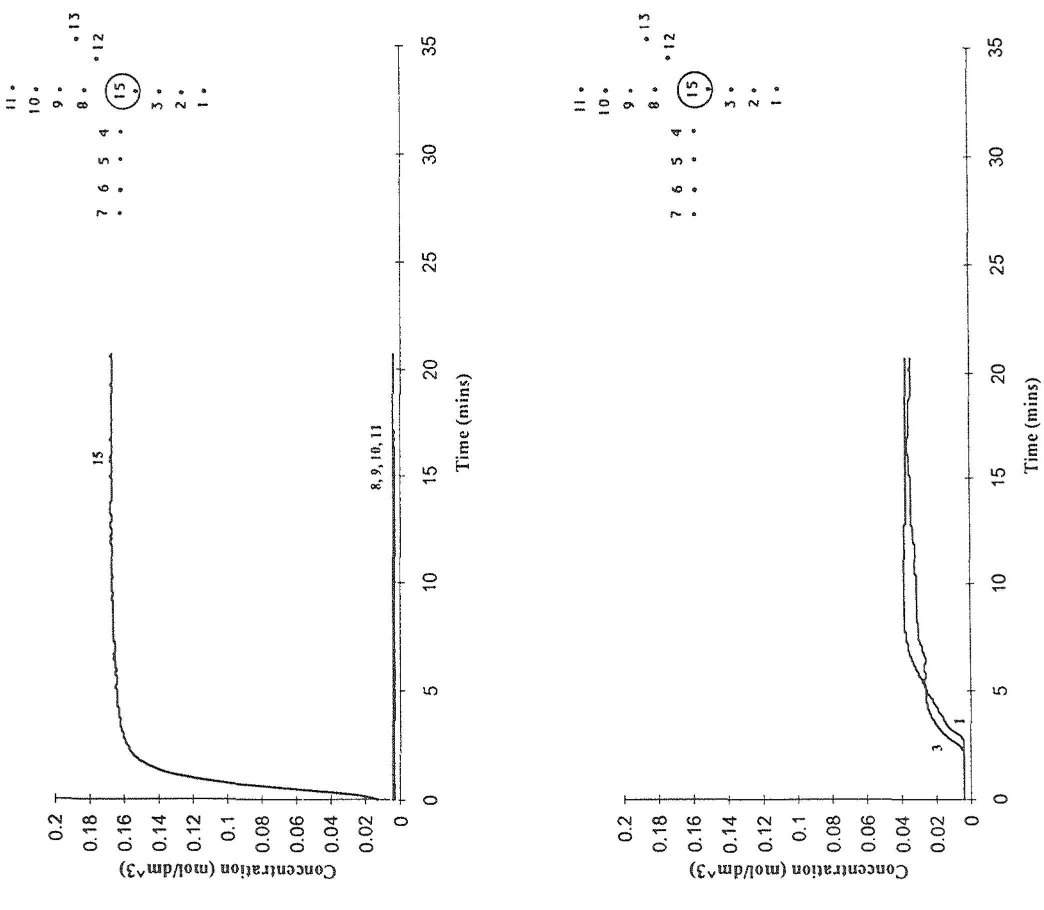

Figure 12a: Concentration Rises Recorded in the Absence of Heat Transfer

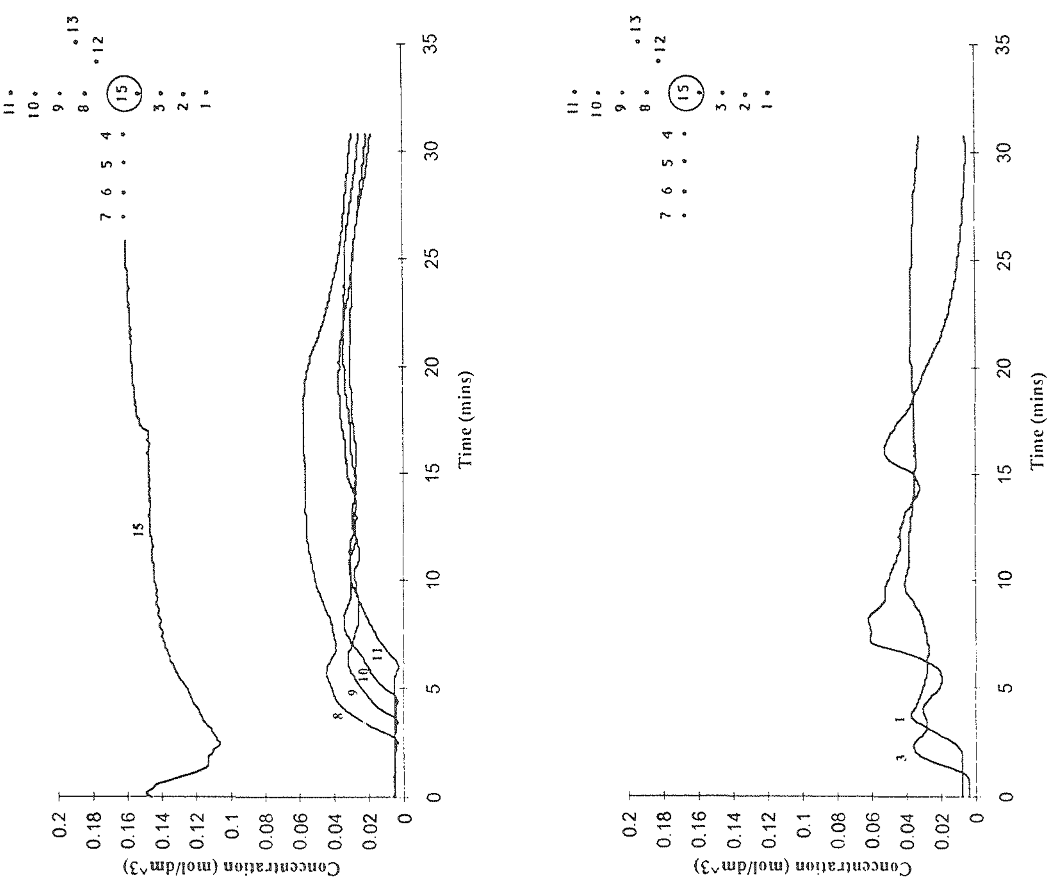

Figure 12b: Concentration Rises Recorded in the Presence of Heat Transfer

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The latter work reported in this paper was carried out at the University of Western Australia, while Dr. Savvidou was on study leave from the University of Cambridge. Financial support for Dr Savvidou's visit from the Mosey Visiting Fellowship and the U.K. Royal society is gratefully acknowledged.

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PHYSICAL AND NUMERICAL MODELLING OF CONSOLIDATION OF MINE TAILINGS

M. Fahey§ and S.H. Toh¶

ABSTRACT

In order to predict the consolidation behaviour of slurried tailings, it is necessary to use large-strain consolidation theory to take account of changes in soil properties during the consolidation process. Such a theory can be incorporated into a numerical model, which has the advantage that it can cope with changes in filling rates, and changes in boundary drainage conditions. The major problem with this type of model is to determine the consolidation parameters for use with the model. The paper summarises the approach adopted at UWA, which makes use of the Geotechnical Centrifuge to derive the model parameters, and also to carry out some limited verification of the model. The paper then describes some results which show what can be obtained with the numerical model, demonstrating the effects of different boundary drainage conditions and different filling rates on density and strength profiles at various times.

1 INTRODUCTION

The proper management of an area used for disposal of slurried tailings, both during and after the active disposal period, requires an understanding of the processes that control the movement of water in the tailings, the rate and final amount of surface settlement, and the changes in the strength profile through the depth of the tailings. This involves understanding the processes of initial sedimentation, self-weight consolidation under various boundary conditions, and formation of surface "crusting" due to the combined effects of water table lowering in the tailings and surface desiccation due to evaporation.

Consolidation of slurried tailings is a process which depends on self-weight stresses, and involves large strains (and hence changes in compressibility and permeability). It is therefore one class of problem which is most ideally studied using a Geotechnical Centrifuge, such as that operated by the Geomechanics Group at the University of Western Australia (an Acutronic model 661). The centrifuge serves two purposes in the tailings consolidation work: tests with simple boundary conditions can be carried out for calibration of the numerical model, and some parametric studies and model verification can be carried out by varying the drainage boundary conditions.

This paper summarises the method of calibrating the numerical model for each new tailings deposit. The model is then used to show the effect of different drainage boundary conditions and rates of tailings disposal on the overall behaviour.

2 CENTRIFUGE MODELLING

Centrifuge modelling is the ideal method of investigating self-weight consolidation of soft soils because it allows the full-scale problem to be properly simulated, but in a much reduced time. When a container of soil is fixed at the end of the rotating arm of a centrifuge, it is subjected to a centripetal acceleration of $Ng = \omega^2 r$, where ω is the angular velocity of the arm, and r is the arm radius. The soil in a centrifuge model has therefore a unit weight ρNg, where ρ is the soil bulk density, and hence a model in the centrifuge has the same stress distribution as a body of soil N times deeper in a $1g$ gravity field. Thus, the centrifuge allows problems to be modelled at a scale of $1/N$ while maintaining true stress similitude.

Because time in consolidation events depends on the square of a characteristic length, consolidation on the centrifuge is N^2 times faster than it takes for the equivalent prototype. Thus, 1 day of consolidation on the centrifuge, at an acceleration of $100g$, is equivalent to 100^2 days (27 years) consolidation at prototype scale.

A description of the centrifuge facility at UWA is provided by Fahey *et al.* (1990). The sample of tailings is contained in a container of rectangular or circular cross section designed to withstand the high stresses of centrifuge testing. The layout of instrumentation for a typical tailings consolidation test is illustrated in Figure 1.

Drainage from the sample during the test can be either just to the top surface (one-way drainage) or to both top and bottom surfaces (two-way drainage). A solenoid valve allows the bottom drainage to be switched on or off at any time. The water table in the bottom drainage layer can be maintained at any level, giving complete control of the base pore pressure during the test. Water that drains to the top surface can be either decanted or left on the surface.

During a centrifuge test, the strength profile can be determined "in-flight" using a cone penetrometer, a miniature shear vane, or a T-bar penetrometer (Stewart and Randolph, 1991). In one case for tests on mineral sands tailings, surface footing tests were also carried out at various stages to assess bearing capacity and foundation stiffness (Toh and Randolph, 1992). The actuators for these types of tests are indicated on Figure 1. As well as permitting vertical loading of the cone or footing, the actuators can also move horizontally, so that cone or

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footing tests can be carried out at more than one location without stopping the centrifuge, allowing strength profiles to be determined at different times during the test.

Surface settlement is monitored using a displacement transducer (LVDT) resting on a small surface bearing plate. The LVDT core is counterweighted using a pulley system to counteract the increase in self-weight with increasing acceleration, thereby preventing it from sinking through the slurry during the early stages of the test while the slurry is still soft. A similar system can be used to monitor settlements at any depth using a plate buried at that depth.

Miniature "Druck" pore pressure transducers are used to monitor the progress of consolidation. By accurately counter-weighting these transducers (in the same manner as with the LVDTs), the transducers settle with the clay specimen during the consolidation process, thereby remaining at the same "material coordinate".

At the end of the test, the sample is dissected to obtain samples for determination of the final density and water content profiles, and to check the final location of pore pressure transducers.

Much of the initial proof testing was carried out using commercially-available kaolin, with a liquid limit of 60 and a plastic limit of 27, but since then the testing has been extended to tailings from the alumina, gold and mineral sands industries. The tailings may be prepared in a slurried state at the same solids content as they are pumped to the disposal area. In some industries, the sand and fines ("slimes") fractions are separated during the extraction process, and some centrifuge tests have been carried out to

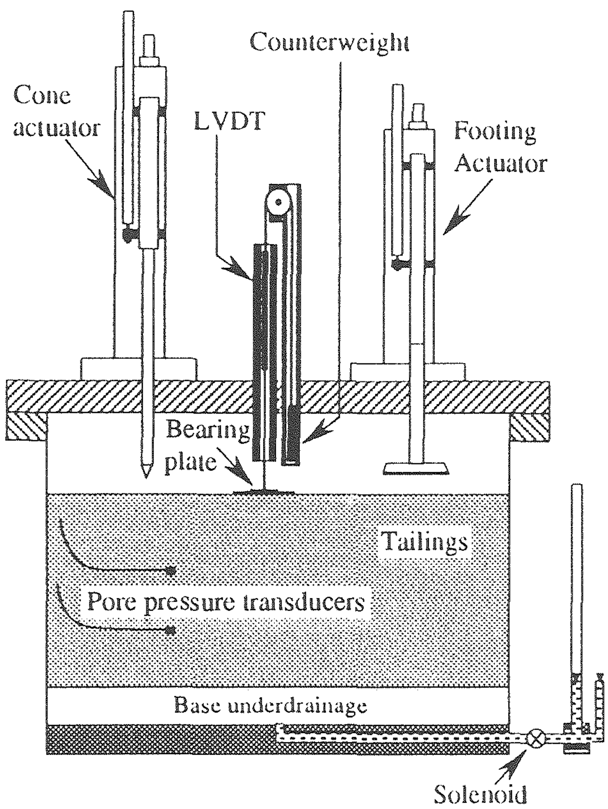

Figure 1. Layout of centrifuge test.

investigate the options of re-blending these fractions before disposal, compared with deposition in layers.

3 NUMERICAL MODELLING

3.1 Large strain consolidation

The consolidation of slurried tailings is a classic example of large strain consolidation – that is, where changes in soil thickness and soil properties (compressibility and permeability in particular) are too large to allow Terzaghi theory to be applied directly. A large-strain consolidation model has been developed by Gibson *et al.* (1967), which allows some of these factors to be taken into account. However, if the finite element or finite difference method is used, there is no need to adopt this type of explicit large-strain formulation, provided an appropriate time step is used in the analysis, self-weight stresses are taken into account, and the geometry and material parameters are updated after each increment. In effect, the small-strain formulation is applied to small increments of consolidation, and the large-strain aspect is dealt with by updating the problem after each increment.

In practice, the numerical approach using the incremental finite element or finite difference method has the advantage that the updating phase after each increment can include addition of fresh tailings at the surface, as would occur in practice during the active life of the disposal area, and changing the boundary drainage conditions such as reduction in permeability or changing the water table in any base filter layers, for example where natural or engineered base drainage is present. Non-homogeneity of the soil skeleton can also be incorporated by grouping the elements into different categories each having different properties.

The assumptions of constant permeability and compressibility in the small strain theory are valid within each increment of consolidation provided the increment size is not loo large. However, some care must be exercised in choosing the size of the time increment, since this affects the stability of the numerical analysis.

In the absence of creep effects, the permeability and compressibility of the soil depend on the void ratio alone. Thus:

$$e = e(\sigma') \qquad (1)$$

and

$$k = k(e) \qquad (2)$$

The actual relationships used are obtained by the fitting procedures described below.

3.2 Suction

Final rehabilitation of a tailings disposal area requires that the surface of the tailings has achieved sufficient strength to allow access onto the surface for placing surface fill (for surface contouring, or for replacing topsoil). Self-weight consolidation with the water table maintained at the surface for either one-way or two-way drainage produces high strength at depth, but very low strength at the surface. However, lowering the water table can overcome this problem, since it results in negative pore pressure (suction) which increases with height above the water table. Fahey and Toh (1992) illustrated this using the case of a 30 m deep layer of tailings consolidated with a base water table maintained at 10 metres above the base. Assuming an initial unit weight of 14 kN/m3, the initial and final stress states are shown in Figures 2(a) and (b), while Figure 2(c) shows the pore pressures at different stages of consolidation. (Note that this Figure takes no account of density or height changes which occur in reality). The suction above the water table results in significant effective stresses, and hence significant strength, right to the top surface.

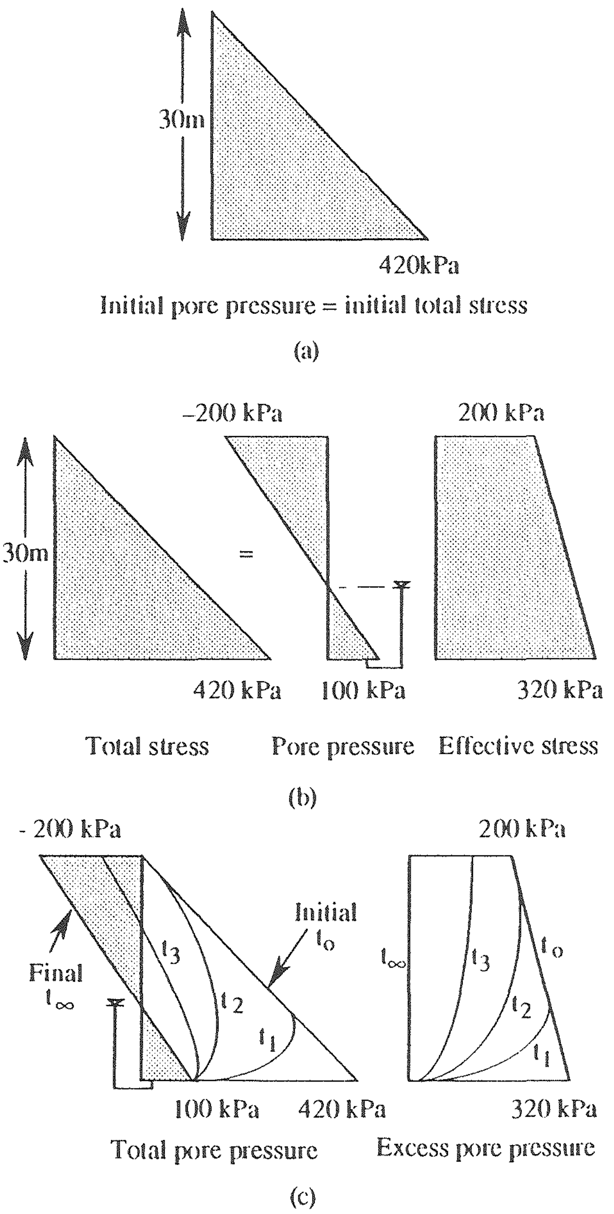

Figure 2. Illustration of process of consolidation from slurry with underdrainage: (a) initial stress and pore pressure; (b) final conditions; (c) schematic representation of pore pressure isochrones during consolidation (after Fahey and Toh, 1992).

Consolidation due to suction cannot continue to increase indefinitely, because eventually the soil starts to de-saturate when the suction at the surface reaches the air entry value for the soil. For any particular soil, this point can be established readily using a shrinkage limit test, since the shrinkage limit corresponds to the point of air entry. A simple version of this test consists of carrying out a standard test for linear shrinkage, but with the addition that the sample in the linear shrinkage mould is measured and weighed at intervals during the drying process. The water content (and hence void ratio) at which shrinkage stops can thereby be established. An example of applying this procedure for kaolin and gold tailings is shown in Figure 3. This information can be incorporated into the model to prevent further suction-induced consolidation after this point is reached.

For the kaolin modelling discussed later in the paper, the suction at the shrinkage limit can be deduced to be very high (certainly more than 1 MPa), which is much higher than can be achieved just by water table lowering in most tailings deposits. However, evaporation from the surface can produce suctions much higher than those required to initiate desaturation. This does not result in further shrinkage, but it can give a very significant increase in shear strength, and hence can play a very important part in rehabilitation of the tailings area.

3.3 Shear strength

The consolidation model does not give shear strengths directly. However, the shear strength can be deduced using the Cam Clay model, and this has been incorporated into the program. This allows the shear strength distribution with depth to be calculated at any stage. The ability to carry out strength measurement on the centrifuge at any stage of the test allows the model predictions of strength to be verified, at least qualitatively. The most convenient strength measurements are carried out using continuous penetration

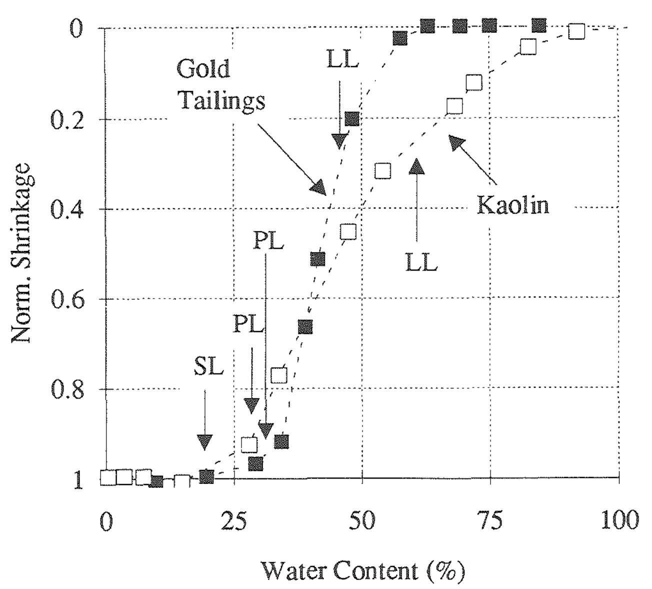

Figure 3. Shrinkage limit measurements on gold tailings and kaolin.

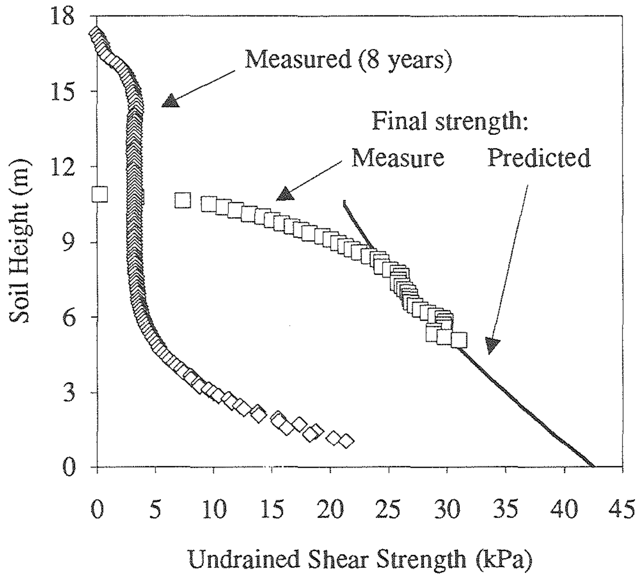

Figure 4. Strength profiles measured with T–bar penetrometer, and final calculated strength profile.

devices, namely the cone penetrometer and the T-bar penetrometer (Stewart and Randolph, 1991). Derivation of strength from the former requires the use of an empirical factor N_q, but for the latter a closed form solution allows the strength to be determined directly.

Figure 4 shows an example of a test in which the T–bar penetrometer was used to measure strengths is discussed by Fahey and Toh (1992). In this Figure, the symbols represent the measured strengths at two different stages of the test, and the line shows the final calculated strength profile. The agreement between the final profiles is good, except right at the surface, where the analysis for the T–bar penetrometer may not be appropriate.

Strength profiling using the cone penetrometer was also used in centrifuge tests on mineral sands tailings in which surface evaporation was not prevented during the test (Randolph *et al.*, 1991). In this case, strengths in the desiccated crust equivalent to q_c values of over 10 MPa were obtained as a result of the evaporation-induced suctions.

3.4 Calibration of numerical model

The numerical model developed at UWA has great flexibility, and can be used to study the effects of varying filling rates, decanting free water appearing on the surface during consolidation, changing drainage boundary conditions, etc. Programs to analyse large-strain consolidation problems already exist elsewhere. However, all such programs require input parameters, and some means of verifying the predictions, if they are to be used with confidence in practice.

In fact, it is possible to do this calibration and verification using a combination of laboratory consolidation tests and observations of the performance of full-scale disposal areas, but the centrifuge offers the most direct method. However, the strategy adopted at UWA is to use the geotechnical centrifuge both for the model verification stage, and to provide soil parameters for each new tailings problem being investigated, as described by Fahey and Toh (1992). The centrifuge test is thus not merely a simulation of field behaviour but may also be utilised to obtain the parameters required for a numerical model.

In the numerical analysis, relationships between voids ratio and effective stress (e–σ') and permeability and void ratio (k–e) for the slurry are required to solve the large strain consolidation problem. In the proposed procedure, the e–σ' relationship is obtained from the water content distribution with depth through the slurry after the completion of consolidation on the centrifuge.

There are (at least) two methods to determine the k–e relationship. The most direct method is by laboratory measurement using either the constant head or the falling head methods. These techniques, presented by Al-Tabbaa and Wood (1987), and Aiban and Znidarcic (1989), have shown good k–e relationship for voids ratios greater than about 2. However, most slurried tailings have higher initial voids ratios, typically greater than 3. These laboratory techniques are not suitable for such soft soils due to the consolidation effect of the seepage stresses which occur during the permeability test

The k–e relationship can conveniently be obtained using a back-analysis method, where the k–e relationship is varied to obtain the best fit between numerical prediction and behaviour observed in either full-scale or centrifuge tests. This relationship can then be used to predict subsequent tests in order to verify both the numerical analysis and the k–e relationship.

In the methodology outlined by Fahey and Toh (1992), centrifuge tests with relatively simple configurations are required to provide the basic parameters, and the numerical model is then used to carry out the parametric study of the disposal options. A variation of the procedure is to use a test with the simplest drainage (drainage to the top surface only, for example) to provide the model parameters, and then use the numerical model with these parameters to predict the behaviour in other tests with different drainage boundary conditions (two-way drainage, with or without lowering of the base water table, for example). For the kaolin used in the numerical analysis described later in this paper, the relationships derived using this procedure were:

$$e = 3.15(\sigma')^{-0.162} \quad \text{.......................................(3)}$$

where σ' is in kPa, and

$$k \text{ (m/day)} = 4.32 \times 10^{-5}\left(\frac{e^{4.25}}{1+e}\right) \quad \text{.........................(4)}$$

The model was then used to predict the behaviour in tests with two-way drainage, with and without water table lowering in the base drainage layer, showing good agreement between the predicted and observed behaviour.

Of course it is recognised that this procedure provides only limited verification of the model and the parameters used. True verification is possible only by comparing the predictions with the observed behaviour in a full-scale problem. The approach described here has been used for a number of projects in Western Australia for the alumina, gold and mineral sands industries. However, to date only one such project presented the opportunity to compare the predictions to the behaviour observed in a fully instrumented full-scale tailings deposit. Predictions in this case can be termed "Class B" predictions (i.e. made after the event, but with the predictions being made before the predictor had access to the results of the full-scale test). Final analysis of these results is still being carried out, and the results will be presented in a forthcoming paper (Fahey *et al.*, 1993). However, it appears at this stage that good agreement can be obtained using the proposed approach.

3.5 Limitations of the model

Apart from the geometry and material property changes which occur in a full-scale tailings deposit, two other very important aspects of real behaviour are not allowed for in the simple scheme outlined above. These are:

- Lowering the water table results in suctions which increase with distance above the water table, as outlined above. However, as suction increases, the stage may be reached where de-saturation starts to occur, so that the simple relationship between pore water pressure and effective stress no longer holds. The suction corresponding to this point can be established using a simple shrinkage limit test, as outlined above. In reality, since the shrinkage limit is generally lower than the plastic limit, and since the effective stress at the plastic limit is generally of the order of 800 kPa (see Wood, 1990), the effective stress corresponding to the shrinkage limit would be higher than 800 kPa.
- In many parts of Australia, the latter stages of consolidation of the soil near the surface may be dominated by evaporation, which will give higher strengths than predicted in a simple consolidation theory. Thus, the approach is conservative, especially in areas of high net evaporation, especially where disposal is in thin layers with some time being left before disposal of subsequent layers for evaporation to have an effect. During the early stages of evaporation, the rate of evaporation is equal to the pan evaporation rate, and this is currently being incorporated into the model as an option for the boundary condition at the soil surface. More sophisticated models will be required for the later stages of evaporation where the rate falls below the pan evaporation rate.

4 APPLICATION OF NUMERICAL MODEL

4.1 Effect of drainage boundary condition

In earlier papers (particularly Fahey and Toh, 1992, Toh and Fahey, 1991 and Toh, Fahey and Kitamura, 1991), measured pore pressure, density and strength profiles in centrifuge tests with various drainage boundary conditions were compared to predictions using the numerical model. In this paper, the types of predictions which can be made using the numerical model will be illustrated. This type of parametric study would typically be undertaken in the early stages of design of a disposal area.

The cases considered are summarised in Table 1. In all cases, the voids ratio on deposition was 3.0. The soil parameters used are those for pure kaolin, obtained as outlined above. The variables considered were:

◆ The base drainage condition: Case 1 had an impermeable base, while all the other cases had a permeable base, but with the water table in the base drainage layer maintained at different heights above the base;

◆ Treatment of water which drained to the surface: In Case 4, the water draining to the top surface was removed immediately (decanted), but in all the other cases, it was allowed to pond on the surface. In the final phase of consolidation where all drainage is towards the base (Cases 2, 3, 5, 6 and 7), this ponded water has to be drawn down through the soil profile before final equilibrium can be reached, thereby adding to the total consolidation time.

◆ Time to deposit the tailings: In Cases 5 and 6, the tailings were deposited at a uniform rate over periods of 10 years and 5 years, respectively. (In fact, tailings were added in monthly intervals, with a depth of 0.167 m and 0.333 m being added per month, respectively). For all other cases, the tailings were deposited instantaneously to a full initial depth of 20 m.

Case	Base head (m)	Surface water	Time to deposit 20 m
1	Impermeable	Ponded	Instantaneous
2	18	Ponded	Instantaneous
3	7	Ponded	Instantaneous
4	7	Decanted	Instantaneous
5	0	Ponded	10 years
6	0	Ponded	5 years
7	0	Ponded	Instantaneous

Table 1. Summary of cases considered in parametric study.

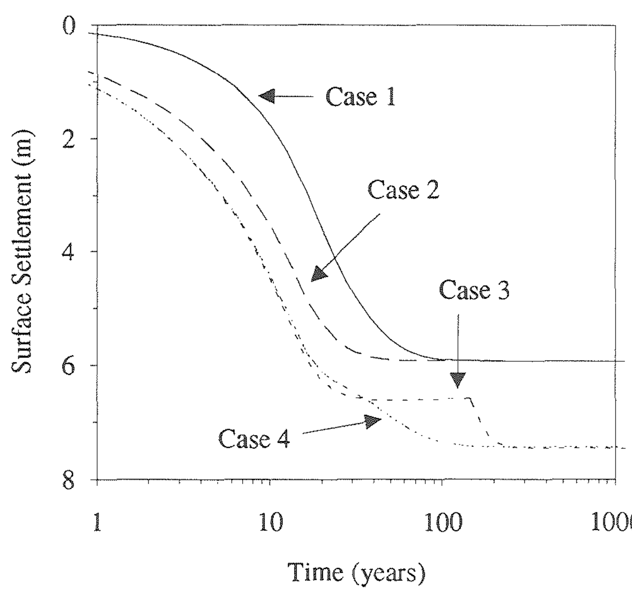

Figure 5. Surface settlements, Cases 1–4.

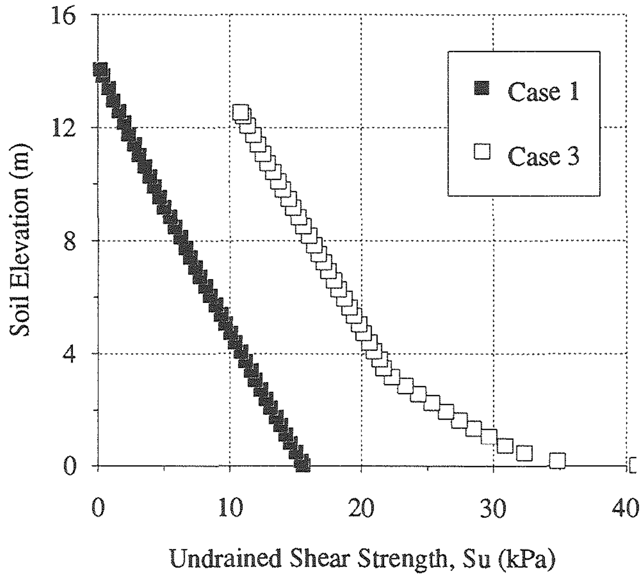

Figure 6. Final strength profiles for Cases 1 and 3.

The surface settlement versus time for Cases 1 to 4 is shown in Figure 5, which illustrates the importance of drainage boundary condition both on the final amount and on the rate of settlement (the use of a logarithmic scale of time tends to mask the contrast between the curves).

Figure 6 shows the strength profiles in Cases 1 and 3 (Cases 2 and 4 are not included as they give identical profiles to Cases 1 and 3, respectively). The effect of the final suction above the water table for Case 3 (and 4) is to give shear strength even at the surface of over 10 kPa, while this strength is only achieved in Case 1 (and 2) at a depth of about 10 m below the surface.

The progress of consolidation for Case 4 is illustrated by the series of plots shown in Figure 7. In these plots, the initial and final conditions are shown by solid square symbols (■) and hollow triangle symbols (△), respectively, with conditions at the intermediate times indicated being

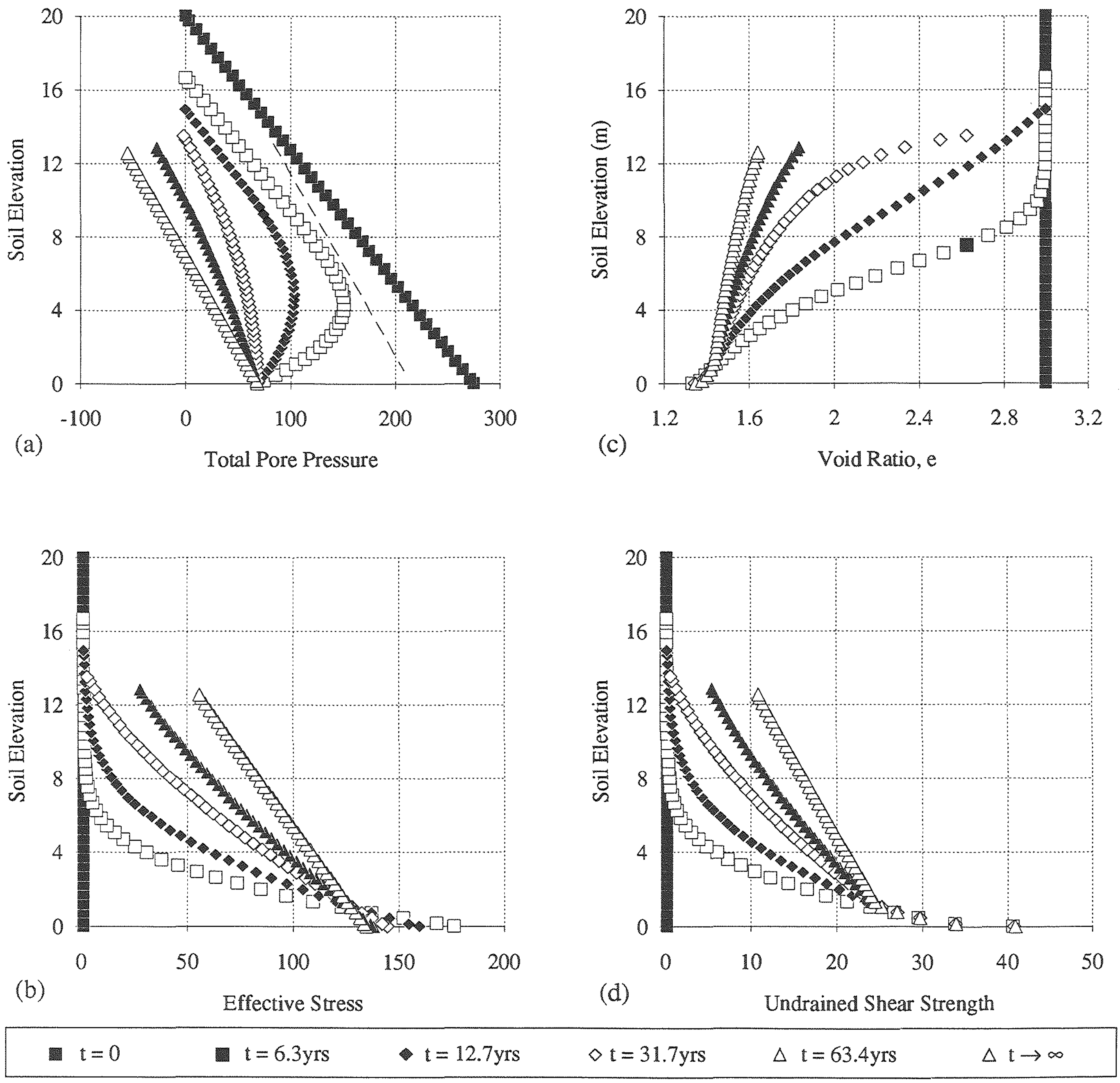

Figure 7. Conditions at different times for Case 4.

shown by the other symbols. Figure 7(a) shows the total pore pressures at these times. Initial conditions show total pore pressure equal to total overburden pressure, but the base pore pressure would fall to the value set in the base drainage layer (70 kPa) immediately after the start of consolidation.

In this Figure, a dashed line at a tangent to the curve for 6.3 years is drawn at the hydrostatic gradient ($du/dz = \gamma_w$). By comparing the gradients of the pore pressure isochrones with the hydrostatic gradient shown by the dashed line, the direction of water flow may be determined, so that the point of tangency with the isochrone divides regions of upward from regions of downward flow. For the case indicated (at t = 6.3 years), drainage is occurring upwards in the zone above 6 metres, and downwards in the zone below that height. This point of inflexion gradually moves upwards, until at a time of about 31.6 years (◇), drainage is totally downwards. (Note however that at this stage, the amount of water flow would be very small). From this point onwards, suctions begin to be generated at the top surface, provided water has not been allowed to pond on the surface. If ponding has been allowed, this water must be drained back into the soil before suctions can initiate. This explains the difference between cases 3 and 4 in Figure 5 – the ponded water in Case 3 continues to drain back into the soil until about 150 years, and the re-starting of settlement at that time is the result of the initiation of suction. The final profile shows a hydrostatic pore pressure, with zero at 7 metres above the base.

It is instructive to note that in this case, the analysis was extended to a total time of over 1000 years to ensure conditions for "infinite time" had been achieved – i.e. to ensure that complete equilibrium had been attained. Even after 316 years (▲), significant excess pore pressures still remained. The parameters used in this analysis are those for pure kaolin, and this might therefore not be representative of any real situation. However, it is also true that many types of tailings contain a significant clay fraction, so that very long times to reach final equilibrium would be expected in some situations.

The effective vertical stress, voids ratio and shear strength profiles corresponding to these pore pressure isochrones are shown in Figures 7(b), (c) and (d), respectively. All these follow a consistent trend. It is clear, for example, that the improvement at the surface due to the low base water table is not felt until suctions are initiated, which is more than 30 years after deposition. Note also that in this case, the final effective stress at the base is slightly lower than the peak value reached shortly after the start of consolidation. This slight overconsolidation is the reason for the change in the final gradient of shear strength close to the base in Figure 7(d) (and Figure 6).

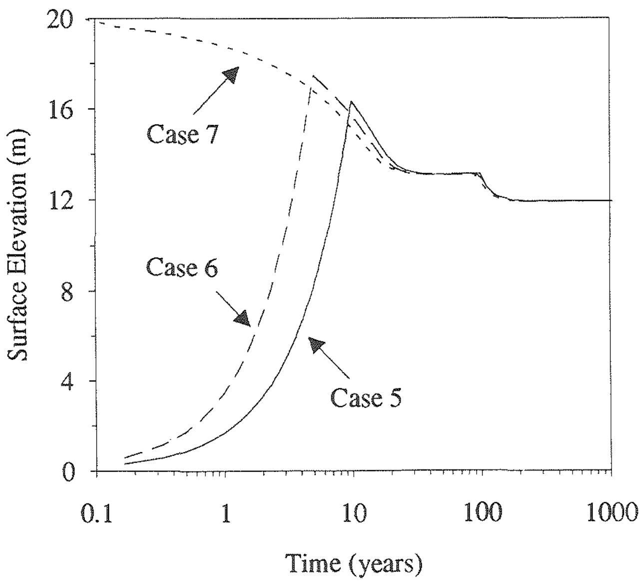

Figure 8. Changes in surface elevation for Cases 5–7.

4.2 Effect of filling rate

The effect of varying the rate of filling the disposal area is examined in Cases 5, 6 and 7. In these three cases, the drainage conditions are identical, but whereas filling is instantaneous for Case 7, filling takes place at a uniform rate over periods of 10 years (0.167 m/month) and 5 years (0.333 m/month) for Cases 5 and 6, respectively.

The changes in the elevation of the tailings surface for these three cases are shown in Figure 8. The maximum heights of filling for Cases 5 and 6 are about 16.2 and 17.5 m respectively, which occurs at the end of deposition (after 5 and 10 years, respectively). When completely filled, the surface elevation in each case is close to that for the case of instantaneous filling. Settlement due to surface suction starts only after 100 years, since in all three cases, water was allowed to pond on the surface rather than being decanted.

This type of calculation would be required in planning a tailings disposal strategy, and shows the importance of being able to model the whole problem if a prediction of the rate of filling of a tailings disposal area is required.

The conditions at different stages of filling and subsequent consolidation for Case 6 are shown in Figure 9. Comparing these plots with those for Case 4 in Figure 7 allows the effect of the extra 7 m of drawdown of the base water table to be appreciated. Thus, for example, the final shear strength at the surface is about double that for Case 4, and the final void ratio profile is much more uniform. However, the long times required to even approach equilibrium should again be noted.

4.3 Changes in soil properties

Inspection of Figures 7(c) or 9(c) shows that the void ratio changes significantly during the process of consolidation, starting from a uniform value of 3.0 in each case, with a final value at the base of about 1.3. In Figure 10, the relationships between permeability and voids ratio (k-e) and voids ratio and effective stress (e–σ') used in the prediction exercise are shown. On this Figure, the vertical dashed lines show the range of voids ratio applicable in this case. Also shown on this Figure is the value of coefficient of consolidation (c_v) obtained by combining permeability and stiffness in the usual way. As the voids ratio reduces from 3.0 to 1.3, it can be seen that the value of c_v varies by about an order of magnitude, as indicated by the arrows on the right-hand axis Thus, it is clear that it is not appropriate to carry out calculations on the assumption of a constant value of c_v.

5 CONCLUSION

The paper has summarised the approach to predicting the consolidation behaviour of mine tailings using a combination of centrifuge testing and numerical modelling. The approach consists of carrying out centrifuge tests on the tailings under simple drainage conditions, and using the results of these tests to provide parameters for a finite difference computer program, which can then be used to examine the effects of changing geometry or drainage conditions, predicting the response to different rates of filling, and determining the final density and strength profiles. In order to demonstrate the types of results which can be obtained, an example of applying the program to the case of a 20 m deep tailings deposit is described.

By carrying out centrifuge tests on the same material, but with different boundary drainage conditions, some verification of the approach can be obtained. However, to date, detailed verification has been possible with only one well-instrumented deposit.

The cases considered in the paper show that significant strength gain can be obtained right to the soil surface if the tailings disposal area has drainage through the base, with

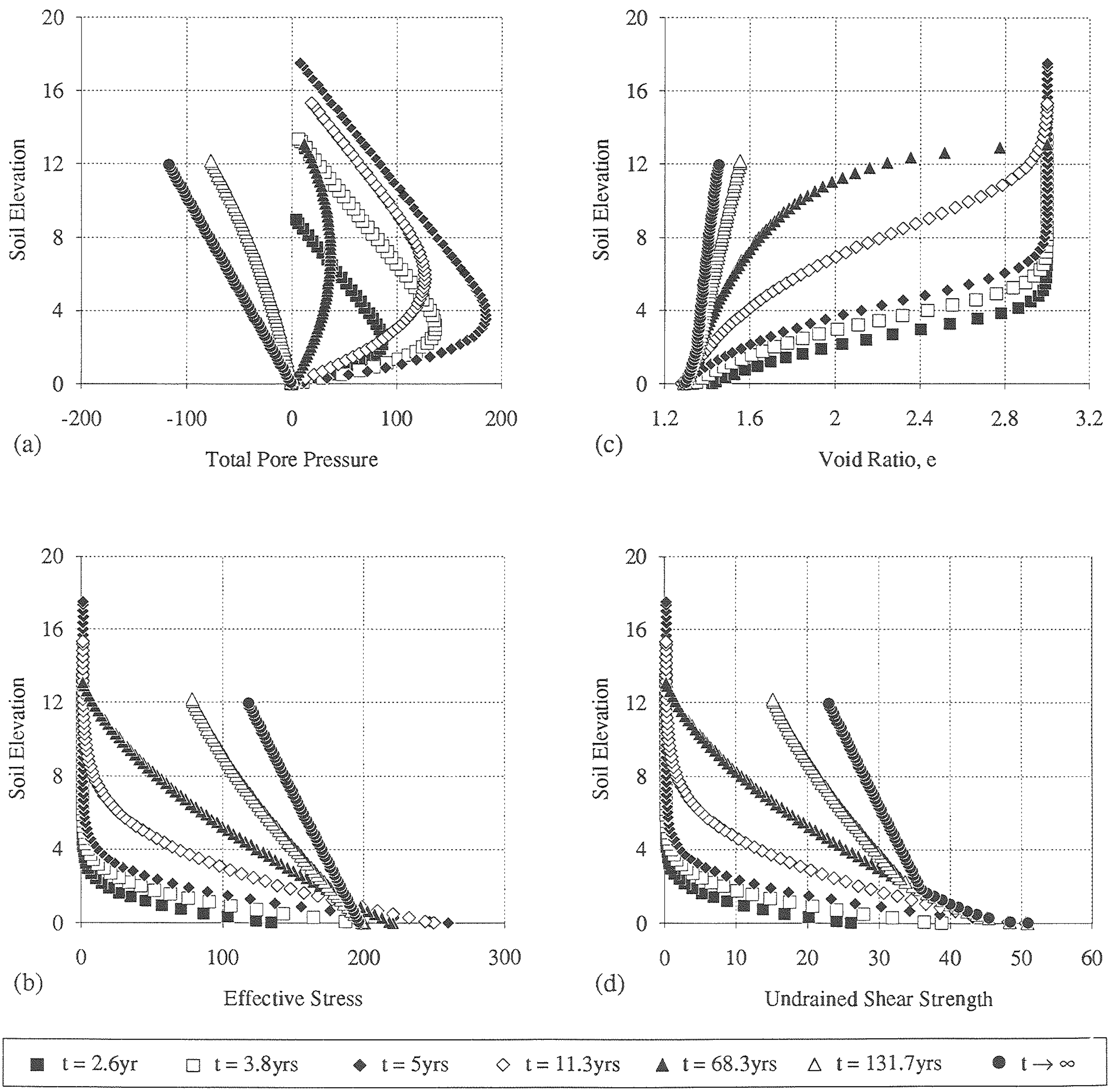

Figure 9. Conditions at different times for Case 6.

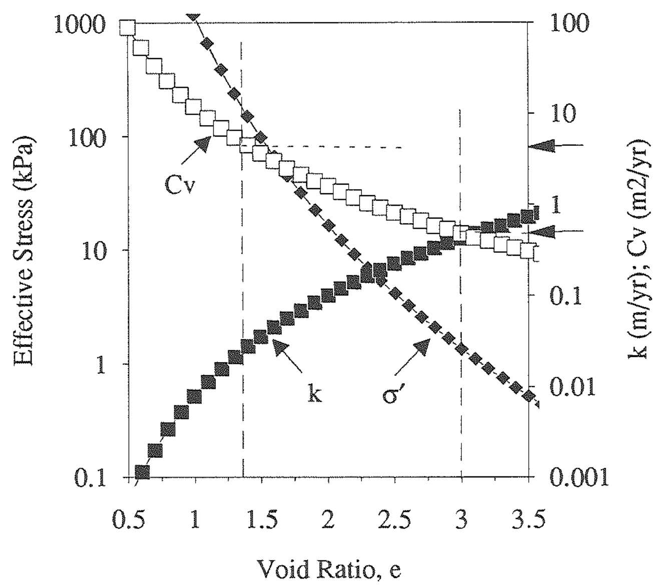

Figure 10. The σ'–e and k–e relationships used in the analysis (and deduced c_v–e relationship).

the water table at the base being maintained at or below the base of the tailings. However, it is also shown that the times for consolidation can be very long, and hence this strength gain may not occur until some time after the end of tailings disposal. In some of the centrifuge tests where evaporation was not prevented, surface desiccation results in much higher strengths being achieved (Randolph *et al.*, 1991).

As stated in the paper, the current version of the numerical model does not take any account of the effects of evaporation. In many parts of Australia, net evaporation rates are very high, and therefore should be taken in to account, especially in assessing the rate of strength gain at the surface. During the early stages of evaporation, the rate of evaporation is equal to the pan evaporation rate, and this is currently being incorporated into the model as an option for the boundary condition at the soil surface. More sophisticated models will be required for the later stages of evaporation where the rate falls below the pan evaporation rate.

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AUDITING OF CONTAMINATED LAND

R.J.PARKER [1]

ABSTRACT

This paper has been prepared to assist persons confronted with the problems associated with contaminated or potentially contaminated land. It provides an outline of the major issues involved in the assessment or auditing of contaminated land. The paper lists reasons why an audit may be required, describes the stages of assessment or auditing and outlines some of the issues involved in planning field and laboratory programmes. The paper then addresses specific matters such as sampling frequency, selection of analytes, quality assurance and the determination of acceptable levels of contamination. The paper concludes with a description of the statutory audit process applying in Victoria and provides some information on the selection of professionals who can assist with the assessment or auditing of contaminated land.

1.0 INTRODUCTION

Disposal of waste to land has been a traditional method of waste management for many centuries. This practice continued through the period of rapid industrialisation of the last century to leave a legacy of polluted soil, groundwater and surface water in most industrialised cities. In the last decade we have seen rapid change in the approach to waste management and uncontrolled disposal of waste to land is no longer acceptable in most developed communities. We are now witnessing the formulation of contaminated land legislation and regulation in most Australian states and this is having impact on the way land is purchased, leased and developed. A wide range of professionals now have to deal with the issues of contaminated land including those in local government, state government, industry, land development and consultants.

With the development of contaminated land legislation and regulation there is a need for government and industry to understand the complexity of the issues and to have an appreciation of the technical difficulties involved in assessing and auditing of contaminated land. This is particularly important in view of current Federal and State government policies regarding the redevelopment of inner-urban land for residential purposes. Given that much of this land has been used for industrial purposes and is therefore likely to have some contamination, it is critical that all sections of the community understand the problems of assessing land contamination, the impact of the contamination that is found in the ground and the implications of setting unrealistically low target levels for clean-up of contamination.

The paper has been written from the perspective of a practitioner involved in various forms of auditing and assessment of contaminated land including the performance of statutory audits in Victoria.

2.0 REASONS FOR AUDIT OR ASSESSMENT

Assessment or auditing of land for contamination may be required in any of the following situations:

- When rezoning industrial land to a more sensitive land use, eg residential.
- When there is transfer of land ownership or occupancy. This may be required by any one of the parties involved including the vendor, purchaser, financier, insurer, lessee or lessor to protect their various interests.
- When contamination is suspected by a land owner or an environmental authority.
- As part of a risk management programme of any facility which has the potential to impact on the environment.
- To meet statutory requirements, eg in Victoria for land rezoning or to remove a site from the Contaminated Sites Register.

3.0 STAGES OF LAND ASSESSMENT

It is extremely difficult to complete a land audit or assessment in a single stage of investigation since the investigator needs to have some idea of what he is looking for if he has any chance of finding it ! It is for this reason that investigations are generally completed in at least two stages.

Based on a survey of members, the Association of Engineering Firms Practicing in the Geosciences concluded that the best description for initial assessment or auditing of land contamination was *Preliminary Site Assessment.* They considered that this term could be used to describe two levels or stages of investigation which involve the following activities:

Level 1 - Historical, ownership and regulatory review and site visit. This stage involves collection of "background data" including historical information such as property titles, records maintained by state and local government agencies, operating information including raw materials, products and wastes, published documents reports, anecdotal information from

(1) Golder Associates Pty Ltd, Melbourne

existing or former employees of a site and published geological and hydrogeological information.

Level 2 - Level 1 plus geophysical or nominal intrusive exploration and sampling; soil, groundwater or surface water analyses. The objective of this stage of work would be to detect contamination (if present) rather than to define its extent.

In conventional application, a Preliminary Site Assessment (PSA) is conducted to determine the likelihood of a site being affected by substances considered "contaminants" by virtue of applicable authorities' definitions of contaminants, hazardous materials , pollutants, et al. There is no clearly defined scope of work required for a PSA. The level of detail required will depend on a number of factors including:

- the history and use of the site and risk to the environment
- the expected future use of the site
- the physical characteristics of the site including subsurface conditions
- the purpose of the assessment
- the risk to the assessor (ie what qualifications the assessor can include with his report).

Detailed investigation may follow the Level 2 Preliminary Site Assessment. The objectives of the detailed investigation will vary depending on the findings of the PSA and the expected use of the site, but could include one or more of the following:

- to confirm that the site is "clean"
- to provide data for design of remedial treatment
- to validate that the site is "clean" following remedial treatment
- to provide further data for preparation of an Audit Certificate (relevant only to Victoria).

4.0 PLANNING OF FIELD AND LABORATORY INVESTIGATIONS

Careful planning is required for the field and laboratory programmes of a PSA. In the planning, decisions have to be made on:

- the areas to be investigated
- the number of samples to be recovered and analysed
- the location and depth of the samples
- the method of sample recovery, handling and storage
- which samples will be analysed and for which analytes.

Collection of background data on the site and an understanding of the behaviour of the potential contaminants is required to enable development of a rational investigation programme. Primary information required in planning will include:

- Topographical, geological and hydrological characteristics of the site.
- Distribution and type of known fill materials.
- Type and location of industrial activity, including nature of the processes and the storage locations of material (including wastes).
- Locations of known spills, leaks and other releases.
- Depth to groundwater and the permeability of the soil and rock.
- The mobility of potential contaminants.
- Environmental sensitivity of the area (ie potential impact of off-site migration).

The following sections briefly describe some of the factors which should be considered in the development of a sampling and analytical programme for contamination assessment. This is not intended to be a detailed discussion of the procedures used in planning and executing contamination assessments, but merely highlights several aspects that should be considered.

5.0 SAMPLING FREQUENCY

The decision of how many and where to sample is a common problem for all assessors of contaminated land. Given the inevitability of budget constraints it is always necessary to carefully plan an investigation to gain maximum information for reasonable cost. It is obvious that <u>all</u> of the soil or groundwater on a site cannot be sampled and therefore design of a programme must consider the number of samples that are required to be statistically meaningful.

There are no universally recognised techniques for determining sample frequency and it is generally up to the assessor to determine the acceptable number of samples. In doing so the assessor must consider:

- *Previous site use.* Sampling may target specific areas where contamination is suspected (for example adjacent to an underground storage tank) or alternatively, grid sampling may be adopted where either a uniform distribution of contamination is suspected or where little is known about the site.
- *The intended use of the site.* For example if the site is to be used for residential purposes then the sampling frequency should reflect the block size, possibly requiring that each and every block is sampled. Alternatively, if the site is to be used for industrial purposes then a lesser number of samples may be appropriate.
- *The type of investigation.* The sampling frequency and layout for a preliminary investigation will be very different to the frequency and layout for a validation programme after clean-up.
- *The mobility of the contaminants.* The mobility of the contaminants will be dependent on both the physical characteristics of the site (eg permeability and depth to water table) and the characteristics of the contaminants (eg ability to sorb to the soil or solubility in water).

- *The liability or risk to be assumed by the assessor or auditor.* Although this is not a technical consideration it is nevertheless a critical aspect of the design of the assessment or audit programme. In Victoria, where the approved auditor assumes significant liability in the issue of a Certificate of Environmental Audit, he may require more intensive sampling than if his certificate was appropriately qualified or referenced.

6.0 SELECTION OF ANALYTES

It is important to understand that analytical procedures are chemical specific and the laboratory will only analyse for the chemicals which are requested. For organic chemicals, techniques are available for identifying and quantifying a very wide range of chemicals (gas chromatography/mass spectrometry). However, this testing can be very expensive and is generally inappropriate for most programmes. Screening techniques are available to identify classes of compounds but often specific identification and quantification is required.

Fortunately, there is a limited number of chemicals that are considered to be hazardous and can be expected to occur in the environment. In the USA, the EPA has published lists of hazardous chemicals for the various regulatory programmes. These lists include no more than a few hundred of compounds. For example in groundwater assessment there is a list of 133 chemicals which are generally considered in any analytical programme ("Priority Pollutants"). In Australia there is no comparable list of contaminants and some professional judgement is required in design of an analytical programme.

It is critical in the design of any analytical programme to have a sound understanding of the nature of chemicals used on a site through an appropriate background study. By completion of such a study it is often possible to limit the number of analytes to a reasonably sized list.

7.0 QUALITY ASSURANCE FOR FIELD AND LABORATORY PROCEDURES

The adoption of rigorous quality assurance and quality control procedures are a fundamental requirement of any assessment for contaminated land. Quality procedures that should be adopted for field and laboratory work are:

Field

- Field sampling techniques should be designed to minimise the occurrence of cross-contamination of samples either from adjacent samples or from sources external to the site. For example in determining the limits of a contaminated area it is important to ensure there is no cross-contamination from heavily contaminated areas to lightly contaminated areas which may impact on the validity of the results.

- Field sampling techniques should be designed to avoid spread of contamination, either by leaving contaminated soil or water on the ground surface or by cross-connecting aquifers (a very serious problem).

- Sampling methods and handling should be designed to minimise alteration of the chemical state of the samples. A major problem is the loss of volatiles from soil and water samples leading to under-estimate of volatile concentrations. Consideration must be given to sample preservation and holding times before analysis.

- Careful planning of the sampling programme is required giving consideration to:

  - sampling approach, eg random, statistically based or facility based

  - data quality objectives; why is the data required ?

Laboratory

- Wherever possible laboratory analyses should be performed using standard methods, preferably recognised by the appropriate authorities. In Australia, analyses should be completed with NATA-endorsement of results.

- Appropriate laboratory quality control procedures should be used. These should include analysis of duplicates, spikes and appropriate use of reference standards. It is often useful to conduct inter-laboratory checks of samples, although it must be appreciated that it is difficult to achieve identical results from two samples of soil. In budgeting for an analytical programme an allowance should be made for quality control testing, generally 10 to 15 % of budget.

- There should be periodic auditing of laboratories, including both systems audits and performance audits.

8.0 ACCEPTABLE LEVELS OF CONTAMINATION

Once sampling and chemical analysis has been completed for a site it is necessary to determine the consequences of the observed concentrations of chemicals with respect to the health of persons using the site and with respect to the impact on the environment. This is one of the most difficult aspects of any site assessment or audit and introduces an area of considerable controversy between industry and the environmentalist. We are often faced with the opposing views regarding what is an acceptable level of contamination to leave on a site. The extreme views are:

- the site operator who says "I've been working here for 40 years and it hasn't hurt me"; versus

- the environmentalist who says "Any level of contamination is unacceptable".

Ideally, it would be best to clean-up to a level which ensured that no contamination remained in soil or groundwater above background levels (contamination can be strictly defined as any concentration of a chemical in the environment which is above its background level). However, it is indisputable that much of our urban environment is contaminated with chemicals at levels above pre-settlement background levels and the cost to return to background levels would be prohibitively expensive. For practicality, therefore we must consider what levels of contamination are appropriate to ensure there is no unacceptable health risk to persons using a site and that there are no unacceptable environmental risks.

There are two broad approaches that can be used to determine the level of acceptable contamination for a site. These are:

- *Prescribed levels of acceptable contamination.* These are typically prepared by regulatory agencies and generally indicate "trigger" levels for certain actions, eg further investigation of the site or clean-up of the site. In some cases these levels make allowance for differing soil types and final land use. However, in most cases they take no account of soil type and are not site specific. Thus many practitioners do not like this approach to determination of acceptance criteria. However, prescribed acceptance criteria and guidelines are extremely useful for small sites and for decision making at the early stages of investigation.

- *Risk assessment.* This is a process where the risks associated with any particular level of contamination are quantified with respect to health and environmental impact. The process involves:

  - data collection and evaluation
  - exposure assessment
  - toxicity assessment
  - risk characterisation.

  A particular contaminant may present a hazard, possibly through a variety of pathways or routes, to one or more receptors or targets, which may vary in importance depending on the intended use of the land. The main groups of receptors or targets which are relevant to the assessment of contaminated land are:

  - humans (workers, persons using the site and people off-site)
  - plants and animals
  - building materials and services.

  For humans in particular, there are both direct and indirect pathways affecting mainly those living or working on the site which include:

  i) ingestion of contaminated soil
  ii) inhalation of vapours or contaminated dust
  iii) dermal contact
  iv) uptake of contaminants in food plants;

  and indirect pathways, also affecting people outside the site which include:

  v)contamination of water resources (surface and ground water)
  vi) contamination of drinking water in pipes running through the contaminated soil
  vii) ingestion through the food chain
  viii) fire or explosion
  ix) inhalation of vapours produced in a fire.

  Computation of an acceptable concentration of a contaminant should take account of the pathways through which the receptors will be exposed to the contaminants and both carcinogenic and chronic health risks. In process of risk assessment many assumptions must be made and ultimately some professional judgement is required in adopting a particular acceptable level of contamination.

9.0 STATUTORY AUDITS

In the state of Victoria a system of statutory auditing has been developed. The Victorian Environment Protection Act makes provision for the appointment of environmental auditors. At the beginning of 1991, six individuals were appointed as auditors for contaminated land with authority under the Act to issue Certificates of Environmental Audit. Under Ministerial Directive Number 1 of the Environment and Planning Act, Certificates of Environmental Audit are required:

- when land which has been used for industrial purposes is to be rezoned for a sensitive land use such as residential use, agricultural land use and some types of public open space

- prior to a site being removed from the register of contaminated sites.

The current form of the certificate requires the auditor to state "*...that I am of the opinion that the condition of the land at the site is neither detrimental nor potentially detrimental to any beneficial use of the land at the site.*"

In its current form the certificate places extreme responsibility on the auditor and this will have an impact on the feasibility of redeveloping industrial land for residential purposes. It is likely that the auditing system will evolve with time to a less restrictive form.

Consideration is also being given to various forms of statutory auditing in other states of Australia, particularly Queensland which seems to be the most advanced on this course.

10.0 SOURCES OF PROFESSIONAL ADVICE

It is important to understand that the conduct of assessments and audits for contaminated land often involves a multi-disciplinary approach. A range of specialist services are required including geologists, hydrogeologists, geotechnical engineers, geochemists, analytical chemists, biologists and toxicologists. If clean-up is required then further then input from other disciplines are needed including civil engineering, chemical engineering and occupational hygienists.

Very few individuals or even organisations (in Australia) have the experience to provide all of these services. In seeking professional advice the owner of site should seek persons or organisations who have a sound understanding of the problems associated with the assessment of contaminated land and can draw together the range of professionals necessary to develop a rational assessment of a site and, if necessary, develop practical solutions for the remedial treatment of contaminated land.

11.0 CONCLUSIONS

The identification and management or clean-up of contaminated soil and groundwater is now an important environmental issue in Australia and one that has the potential to impact significantly on industry and the economy in general. To date, the environmental authorities in Australia have been able to adopt a pragmatic approach to land contamination and are prepared to accept relatively high levels of contamination on industrially or commercially zoned land provided that the contamination does not constitute a hazard to the persons using the land or to the environment. Nevertheless, owners of industrial land and developers of former industrial land will have to be vigilant to avoid liability and/or loss of value of their property. They will have to understand their risks in this area of environmental law and seek advice from professionals with sound experience in the area of assessment and auditing of contaminated land to assist them. In seeking appropriate advice and through careful negotiation with the environmental authorities, in many instances, it will be possible to develop contamination management strategies that minimises both risk to the environment and cost to the site owner or developer.

GEOMEMBRANE APPLICATIONS IN AUSTRALIA [1]

R.J. PARKER [2] and M.A. SADLIER [3]

ABSTRACT

This paper provides an overview of the application of geomembranes in Australia and relates the current trends in use to the environmental regulatory control now applicable. The paper presents examples of geomembrane use in Australia which effectively provides a history of usage and some indication of where future trends may lie.

INTRODUCTION

There has only been limited use of geomembranes in Australia and the current regulatory framework allows considerable flexibility in approach to disposal of wastes. Where there has been a requirement to contain waste, compacted clay has generally been the favoured choice for formation of low permeability barriers.

During the 1980's there was increased use of geomembranes in Australia for lining of waste and other containment structures. However, the extent of use of geomembranes is considerably less than in the USA even taking account of population differences. Nevertheless, the use is increasing and will continue to increase as the regulatory authorities require increased application and improved performance of waste containment systems.

This paper has been prepared to provide an outline of the regulatory environment which currently exists in Australia and the impact that this has had on the use of lining systems for waste containment. In addition the paper documents the likely future directions for lining requirements in Australia.

REGULATORY FRAMEWORK

In discussing the use of geomembranes in Australia it is important to understand the regulatory framework within the country and the factors which influence environmental control of wastes. Although Australia is considered to be an arid country, there is only limited reliance on use of groundwater for domestic purposes and this is mainly in rural areas. In many areas the groundwater is brackish to saline, thus limiting the use of the water.

The limited use of groundwater for domestic purposes, the limited manufacturing industry and the sparse population of Australia combine to produce an environmental regulatory framework very different to those of North America and Europe. Up until very recently, the approach to disposal of industrial, mining and domestic waste has been based on the principle of "dilute and disperse". As long as the waste was placed in a confined area and was ultimately out of sight, limited control was placed on the disposal process. This attitude is now changing rapidly and we are seeing the development of a regulatory framework that will impose much greater control over the disposal of all forms of waste.

In Australia, environmental legislation and regulation is largely a state matter. Federal government can only control environmental matters through the use of financial controls on the states, although consideration is being given to formation of a national Environment Protection Authority. Each state within Australia has developed separate approaches to environmental legislation and regulation so that there has been a diversity in control measures required for waste disposal. In particular, there is seen to be a significant difference in environmental controls between so-called "manufacturing states" and the "mining states".

As environmental awareness changes within the community and attitudes to environmental responsibility and liability change within industry and government, we are seeing rapid changes in environmental regulatory control. Although there is still a diversity between the states, evidence of change in the approach to control of waste disposal and concern over contamination is seen in the following:

- Engineered containment systems have been constructed or are proposed for several landfills in at least three states.
- Most states are now requiring consideration to be given to closure of waste disposal sites in the initial planning phase. Greater attention is being given to issues such as appropriate capping measures and gas control.
- Most states are now concerned with the issue of contamination of soil and groundwater and at least three states have published guidelines for assessment of contaminated land and one is establishing a formal system of auditing of contaminated land.

GENERAL APPROACH

Australian use of geomembranes has largely been in applications for mining, industrial and public health areas and it has only been in recent times that lining has been considered in waste disposal. Some of the reasons for this are the relatively low population densities, the lack of dependence on

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(1) This paper was first presented at Geosynthetics '91 Conference, Atlanta, USA.

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groundwater for public supplies and a record with early liner types of poor ultra violet (UV) light exposure performance in a country where high UV light exposures occur.

Until the advent of heap leach mineral extraction most geomembrane applications were for water or waste water containment. Heap leaching became widespread during the 1980's and helped to develop confidence in liner performance as installations intended for short term service proved to have longer service capacity. The attention has now shifted more to environmental protection in a broader sense as well as solid or liquid waste containment and treatment including capping of existing waste deposits and covers for anaerobic processes.

Since there is limited regulatory control, the geomembrane option for lining is still chosen or not chosen on the basis of an economic life cost appraisal after comparison with other options that are considered viable. These other options may include recycling or processing, cartage to remote sites or conventional clay soil or concrete construction. As experience develops and confidence grows, the geomembrane option is being accorded a longer service life and is tending to compare more favourably, particularly, in areas where there are limited supplies of clay soil.

The following sections describe examples of geomembrane use in Australia. These examples are discussed partly in chronological order and thus provide a "potted history" of Australian geomembrane use.

RED MUD STORAGE AREAS, WESTERN AUSTRALIA

One of the first large scale uses of geomembranes in Australia was at Alcoa of Australia's alumina works in Western Australia. Of the three refineries operated by Alcoa, the Kwinana Works, just to the south of Perth, was the first to use geomembranes on a large scale for a Cooling Pond and then a red mud storage site known as Area H.

The near surface geology of the Kwinana area comprises dunal sand overlying variable limestone (calcarenite). Shallow groundwater in the area is used for industrial and agricultural purposes. Early use of thin (less than 0.4m thick) clay liners (for Red Mud Storage Areas A, B, C and F) resulted in some leakage of caustic liquor to the groundwater. The adoption of such thin clay lining was largely dictated by the significant cost of transporting clay some 20km from the nearest substantial borrow area. Specific problems with the clay liners were attributed to the difficulty of ensuring the integrity of a thin clay layer over large areas (the surface area of each pond varies between 20 and 100 ha) and the occurrence of shrinkage cracks between construction and filling.

As a result of problems with the early storage areas it was decided that future containment systems should use a composite liner system comprising compacted clay and geomembrane. It was considered that such an approach would be more economical than construction of a thicker compacted clay liner.

The adopted liner design for the Cooling Pond (area of about 15hA) and Residue Storage Area H (area of 45hA) was as follows, in ascending sequence:

- 0.5m of compacted clay, placed at or wet of optimum moisture content
- 0.76mm thick PVC geomembrane, field welded and tested by air-lance
- 1m of sand to provide an underdrain to the red mud and as a protective layer from traffic.

A pipe network was constructed in the sand layer to facilitate liquor collection. The underdrain was required to assist with consolidation and hence densification and as a measure to reduce liquor head on the liner system.

Subsequent to the construction of the Kwinana facilities in 1980 and 1981, Alcoa constructed similar lining systems for other red mud storage areas in Western Australia and in recent years they have constructed several facilities using HDPE geomembranes. Alcoa's early use of PVC enabled a fabrication industry to be established in Western Australia and considerable use was made of PVC lining systems for water retention structures and in the resurgent Australian gold industry in the early 1980's.

PERSEVERANCE GOLD HEAP LEACH PAD, VICTORIA

Following the large scale use of geomembranes by Alcoa, the next major development with geomembranes has been use for lining systems for heap leach pads. With the introduction of HDPE membranes into Australia, the gold industry quickly changed from use of PVC to HDPE. There has now been considerable use of HDPE for heap leach pads throughout the gold mining areas of Western Australia, Northern Territory and Queensland. The following example of geomembrane use for a heap leach pad is from the State of Victoria. This site is used as an example of heap leach pad construction since it is one of the few in Australia that has close engineering control during construction.

The Perseverance Gold Mine is at Nagambie about 120km north of Melbourne in an area of traditional mixed farming and wine production. It is an open pit mine with the ore being crushed and treated by cyanide leaching in a heap leach up to 30m high with an area of some 80,000m^2 with ancillary pondage.

The immediate subsoil conditions comprise high plasticity clays and the 1.0mm thick HDPE geomembrane liner was installed directly over the prepared and compacted clay base. Delays in the issue of mining and environmental permits pushed the liner installation window from the dry, hot summer of 1989 into the winter which arrived with plenty of early rain.

Conditions for deployment and field welding of the 6.86m wide HDPE sheet became extremely difficult with wind damage to some of the liner and an unworkable wet clay surface. Non-woven polypropylene geotextile fabric was used extensively to improve working conditions and the liner was deployed largely by winching from fixed locations. This demanded new operator skills in weather watching to predict wind shifts and to take protective action. The majority of the welding was carried out using fusion welding plant with some extrusion welding.

The installation of the geomembrane was under the direction of mine staff with independent quality control being provided by a consulting engineer approved by the Victorian Environment Protection Authority. All work was inspected by the quality control engineer and welding was fully tested by non-destructive methods and some destructive testing.

Gold leaching operations commenced in September 1989 and proceeded satisfactorily with a second stage pad liner being installed in early 1990 under relatively good conditions in the preferred summer period.

HENDERSON LANDFILL, WESTERN AUSTRALIA

This is the first use of a synthetic liner for a landfill in Australia. The Henderson Landfill site is located near Perth in Western Australia within the City of Cockburn (just north of Alcoa's red mud storage areas at Kwinana). The near surface geology comprises dunal sand over limestone with shallow groundwater used for industrial, agricultural and limited domestic purposes. The general area is heavily industrialised and the general waste stream includes many potential pollutants from industry as well as the normal domestic waste.

Planners were essentially left with two choices for this facility. The first was to establish a transfer station within the municipality and consolidate and cart the waste to a remote, geologically secure (and less sensitive) site. The second was to establish a landfill within the municipality which was required to incorporate an adequate liner and leachate collection system. Costing comparisons put the cost of the first option at about A$30 per tonne with about 40km of haulage and the second at about A$16 per tonne including the premium for lining which was estimated at A$4 per tonne.

The site itself is an old limestone quarry with high permeability base and the water table is normally about 3m below the quarry floor. Site preparation involved little more than trimming the site into two initial cells, as indicated on Figure 1 (Halpern Glick Maunsell, 1990a). A clay liner was installed over those parts of the site where the base was less than 3m above the water table; a requirement of the local EPA.

The liner itself is 2.0mm thick HDPE liner in 6.86m wide seamless rolls. It was welded together on site with a combination of fusion and extrusion welding techniques supplemented by a program of non-destructive and destructive testing. Total area is about 60,000m^2 and the complete installation took about six weeks.

The liner was covered with a protective cover of 300mm of sand and a further 300mm of crushed limestone which combine to provide a drainage layer with collection pipes and an operational surface. Leachate is collected via sumps for recirculation and eventual treatment.

GOSNELLS LANDFILL, WESTERN AUSTRALIA

This facility is in the City of Gosnells near Perth in Western Australia and it started life as an industrial liquid waste collection pit and has since been topped up with domestic waste prior to the installation of a HDPE cover.

The original pit came into service around 1979 and was constructed with a liner using a mix of local clay and bentonite in an area of generally clay soils. There has been some

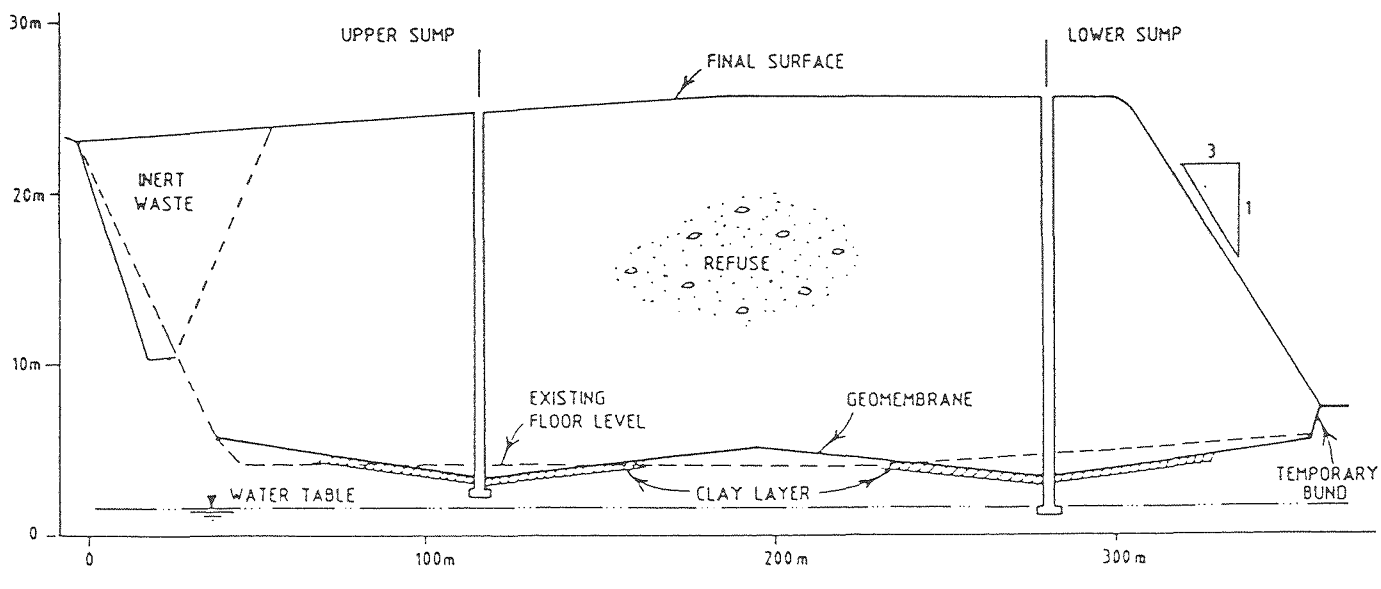

Figure 1. Cross-section - Henderson Landfill

evidence of local soil contamination and several incidents of stormwater overtopping occurred around 1987 and 1988. The liquid waste comprised a mixture of hydrocarbons and had formed a heavy sludge at the base of the pond. As a preparation to final capping the pit has been receiving solid domestic waste as landfill to a depth of about 3 metres. The surface has since become relatively firm and was able to support D7 bulldozer (with a track bearing pressure of about 10 kPa) operations without difficulty.

The cap has the following layers, as illustrated in Figure 2 (Halpern Glick Maunsell, 1990b):

- Sandy Loam - Soil Cover - 300mm
- Clean Sand - 100mm
- 1.0mm thick HDPE
- Clean Sand - 100mm
- Clay Cover - 300mm

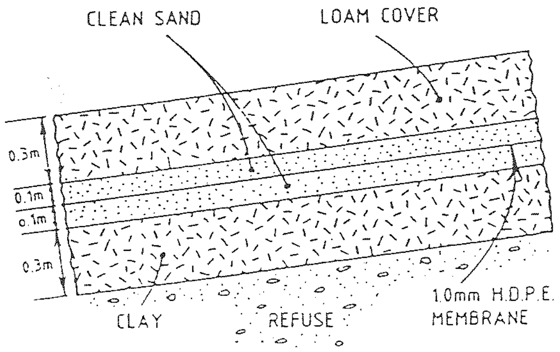

Figure 2. Capping Design - Gosnells Landfill

The plan dimensions are 132m by 58m and the cover crown is superelevated by about 3.5m relative to the perimeter which is restrained by anchor trenches. Gas vents are fitted across the crown and around the edges.

The cover is to be constructed from 1.0mm thick HDPE liner material supplied in 6.86m wide seamless rolls and welded using a combination of fusion and extrusion welding supported by non-destructive and destructive testing.

To the knowledge of the authors, the Gosnells site will be the first use of geomembranes in Australia for capping of waste. However, there are at least two other sites in the design phase which will involve capping using composite liner systems. These are a refinery tailings pond near Perth and an acid/oil sludge disposal site in Brisbane (Queensland).

BRISBANE CITY COUNCIL WASTE DISPOSAL CONTRACT, QUEENSLAND

The City of Brisbane is a municipality serving a population of about 1 million people. Tenders were called early in 1990 for a contract for waste collection and disposal of the entire Brisbane municipality for the next 30 years. Tendering for the contract attracted several bids, although at the time of writing these have been narrowed down to two remaining bids both of which involve use of geomembranes in combination with other lining materials. The following sections describe the proposed lining systems for each of the landfills, using information obtained from publicly available information (References 3 and 4).

Proposed Rochedale Landfill The proposed Rochedale site (Pacific Waste Management, 1990) is located in a former brick clay pit located to the south of the Brisbane CBD. The floor of the pit is in clayey soil and is generally above the water table although there is evidence of spring activity in parts of the site.

The proposed liner design is illustrated in Figure 3 and comprises the following elements:

. prepared subgrade (including sub-liner groundwater drainage system)

. 0.9m of compacted local clay soil to have in situ permeability of not less than 1 x 10^{-9}m/s

. 1.5mm HDPE geomembrane

. leachate collection system comprising geonet (where required), geotextile and selected porous fill.

Subgrade preparation will involve levelling of the base and preparation of batters. Final capping of the site will involve a 1m thickness of compacted clay covered by topsoil.

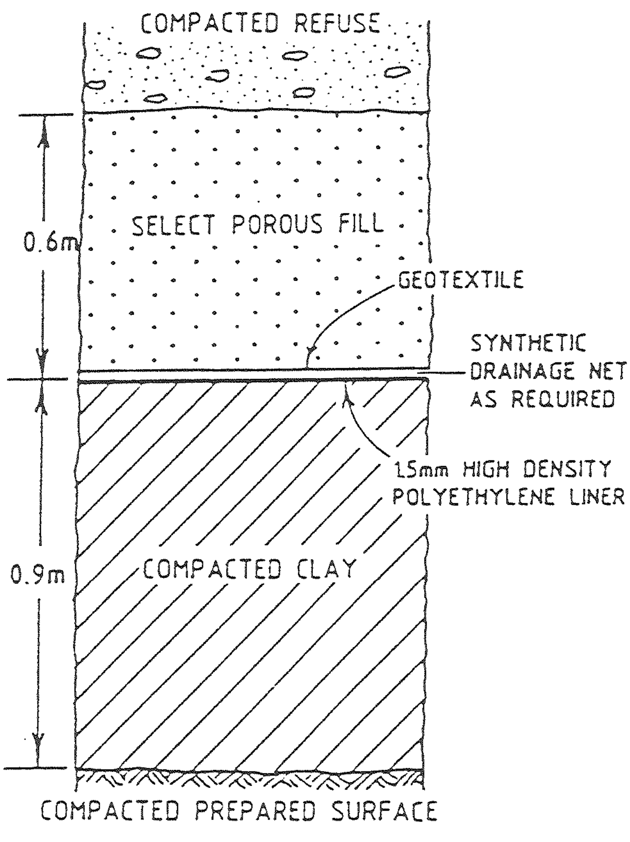

Figure 3 Proposed Base Liner Rochedale Landfill

Proposed Swanbank Landfill The proposed Swanbank Landfill (Railwaste Technology, 1990) is to be located in the Shire of Moreton located on the western boundary of the City of Brisbane. The site is a former open cut coal mine used to supply coal to the Swanbank Power Station. A cross-section of the proposed liner system is illustrated as Figure 4.

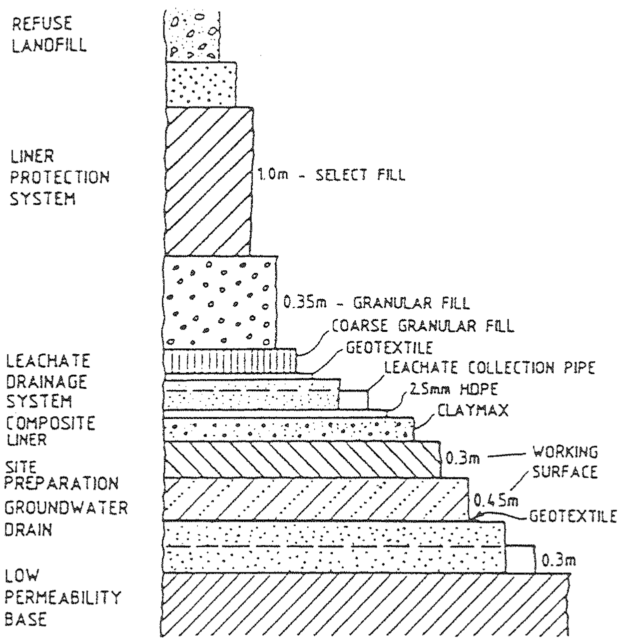

Figure 4. ***Proposed Base Liner Swanbank Landfill***

Once the site has been shaped and prepared, a system of groundwater drains will be installed at the base of each landfill cell. These drains will consist of a trench of granular material excavated into the shaped, compacted low permeability base. Overlying the groundwater drainage system will be a geotextile and a bedding layer of non-carbonaceous material placed to provide a bedding for construction of the composite liner.

The composite liner proposed will consist of a 2.5mm thick HDPE liner underlain by a bentonite/geotextile composite liner. The bentonite liner is proposed to protect the HDPE from protrusions and to provide a back-up liner to the HDPE.

The leachate collection system above the liner will comprise ascending layers of geonet, geotextile, 0.15m fine granular layer (<25mm) and 0.35m coarse granular layer (<150mm). The leachate drainage system will be overlain by 1.0m of compacted waste to provide a working platform which in turn will be overlain by a non-combustible layer of waste as a final protection over the lining system.

Because of concern over the potential for combustion of the underlying coal strata, provision will be made for monitoring of temperature in the groundwater drainage system. If excessive temperature is monitored, water will be recycled through the groundwater drain to reduce temperature.

AQUACULTURE

There are many innovative uses for geomembranes being considered in Australia, some of which are following overseas trends. These include geomembranes for sludge digesters, cut-offs for existing dams, and aquaculture. The use of geomembranes for lining of aquaculture ponds is described below as an example of one of these innovative uses.

In Australian coastal regions interest is growing in the use of membrane liners in the establishment of efficient environments for the farming of high protein and gourmet food sources such as fish, prawns, and crayfish. The major requirements are relatively warm, stable water temperatures, clean water and lagoons shaped to permit rapid harvest. Nutrition requirements are supplemented at controlled levels as cultivation proceeds.

Many early ventures used polyvinylchloride and modified polyethylene liners and suffered from UV light degradation or animal penetration. HDPE contains no plasticisers or additives and provides excellent UV light performance without attracting animals or insects in search of food. Wide roll widths allow for operator installation without welding (narrow pond widths are chosen so that only one width of HDPE is required to avoid need for welding).

There are now several successful farms in northern New South Wales producing fresh water crayfish for gourmet markets and there are proposals in hand to use spent sea water from power station cooling to cultivate seasonal tropical fish.

FUTURE DIRECTIONS

The mining industry in Australia has enjoyed a buoyant period which is now slowing down as commodity prices subside and new taxation measures on gold production take effect. Geomembrane use is likely to continue for pondages and heap leach pads in the mining industry but at a reduced level of activity.

It can be expected that there will be increasing environmental awareness and greater regulatory control for the disposal of waste in Australia. This is likely to lead to increased requirements for containment of waste disposal systems where natural geological containment is not an option. If current trends continue it is likely that regulatory authorities will assess each individual site on its merits with both natural and artificial lining systems being accepted where appropriate.

Where artificial lining systems are required, it can be expected that compacted clay, geomembranes or composite systems will be selected depending in the cost effectiveness of each system. Traditionally, compacted clay soil has been used as the usual medium when lining for waste containment is considered. However, geomembranes are gaining acceptance as an alternative to clay for use in composite systems. It can be expected that a conservative view will apply to the further introduction of geomembranes so it will be a matter of establishing performance records in existing applications and demonstrating that geomembranes provide an effective alternative or adjunct to clay liners.

In this environment it can be expected that geomembrane use will grow in Australia but on a basis of continual enhancement of performance and cost effectiveness. If there is to be growth in the use of geomembranes in a relatively unregulated environment it will be necessary to encourage a quality image based on material performance and selection, proper design and detailing, appropriate installation and quality assurance programs. It will be necessary to educate owners that quality lining systems will only be achieved if all of these aspects are handled appropriately by experienced engineers, suppliers and fabricators.

CONCLUSIONS

Geomembrane use in Australia is increasing at a significant rate but does not have the impetus provided by centralised regulations and technical guidance which would give rise to extensive environmental applications. There are geographical and hydrogeological reasons for the less regulated approach to environmental matters in Australia. However, geomembrane use will continue to increase on the basis of economic appraisal of control measures and provided that performance standards are maintained.

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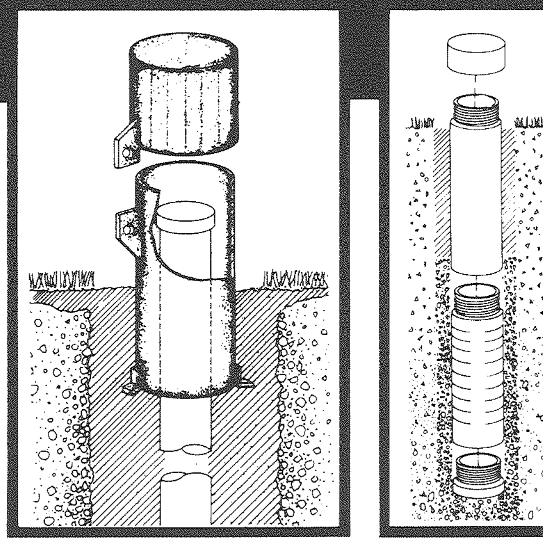

GEOSYNTHETIC CONTAINMENTS IN ENVIRONMENTAL PROTECTION[1]

M. A. SADLIER, MIEAust., CPEng. [2]

SUMMARY

As much as we plan and implement programs for waste reduction and recycling we will continue to need waste disposal and treatment facilities such as lagoons and landfills for both hazardous and non - hazardous waste. We have a collective responsibility to ensure that the environment is protected from undesirable discharges from these facilities.

Geosynthetic materials are widely used in storage areas such as landfill leachate containment, landfill capping, reservoir liners and covers as well as for process containment for industrial and environmental applications. This paper reviews these systems particularly in relation to the extensive USA experience and looks toward those areas where we can make better use of their potential.

Geosynthetics have the capacity to overcome many of the problems experienced in the Asian region where geotechnical construction is often hampered by heavy monsoon flooding, poor soil conditions and high subsoil water levels.

1.0 INTRODUCTION

Much of the growth in use of synthetic liners in North America and Europe has been driven by regulatory frameworks which in the case of landfills demand fail-safe containment and leachate collection systems which have employed multiple layer combinations of 'natural' and synthetic materials. Because of our sometimes lesser population densities and lesser dependence on ground water for public supplies as well as an adherence to traditional disposal and dispersal methods we have not been so concerned to prevent groundwater contamination and for landfills have been willing to rely on the 'dilute and disperse' principle. In SE Asia the use of synthetic liners in waste containment has also been limited. We are now seeing an increasing concern for ground water protection and we can take advantage of others' experience with different liner systems and landfill capping systems.

In addition to their growing use in waste disposal and waste water treatment lagoons synthetic liners have been used frequently in Asia and in Australia for water reservoirs and on a more limited basis for floating reservoir covers and for covers to sewerage lagoons to enable them to function as anaerobic digesters.

(1) Based on a paper originally presented at the 'Baucon - New Frontiers' Conference in Singapore April 1991 when the author was an employee of Polyfelt Geosynthetics.

(2) Geosynthetic Consultants Australia, Melbourne

2.0 LINER TYPES

Traditionally low permeability soils or clay liners have been used in earthworks to provide control of liquid migration and it is highly desirable to locate a secure landfill within a natural deposit of low permeability soil. However such sites are harder to find and the cost of material haulage and construction of clay liners has been steadily increasing. As more importance is placed on the ultimate performance of liners the attention to proper placement, compaction and quality control has served to increase the relative cost of clay liner construction.

Synthetic liners have been improving in many aspects in recent years and can now offer excellent chemical and weathering resistance with positive installation and quality assurance techniques that have lead to an increasing level of confidence.

A variety of synthetic liners such as butyl rubber, polyvinyl chloride (PVC), chlorosulphonated polyethylene (CSPE), chlorinated polyethylene (CPE), Ethylene Propylene Diene Terpolymer (EPDM) and elasticised polyolefins have been used over the years in pursuit of an ideal combination of chemical resistance, weathering performance, flexibility and weldability. Many of these involve the use of additives or polymer modifiers which help performance in some respects but detract in others. For instance modification of the basic polyethylene structure (CPE, CSPE) to improve weldability and flexibility has had a detrimental effect on the weathering and chemical resistance. Plasticisers used to provide flexibility in other polymers may dissipate or leach out over time or even encourage liner consumption by animals.

A relatively recent innovation in terms of lining technology, High Density Polyethylene (HDPE) has established itself quickly as the liner of choice for both solid and liquid waste containment. Quality HDPE liners are based on pipe grade polymer resins with less than 2% carbon black and no other additives which can dissipate over time. They are produced in wide (6 m plus) sheets and recent developments in welding technology have made their field installation reliable and efficient. HDPE provides excellent weathering and chemical resistance and a different grade of polyethylene polymer, Very Low Density Polyethylene (VLDPE) can be used when greater flexibility is desired.

3.0 LANDFILL LINERS

In Australia the use of 'natural' or synthetic liners to create secure landfills has not been widespread and has only been chosen as an option in environmentally sensitive locations or when the waste stream was seen to provide particular hazards. In recent times synthetic liners have been chosen on occasions as a result of a pragmatic cost/benefit examination of the alternatives and a recognition of the difficulties involved in exercising control over the materials which are directed to landfill which can result in leachates and sludges which are difficult to identify 'cocktails' of different reagents.

3.1 Henderson Landfill

The Henderson landfill liner project was the first use of a synthetic liner for a landfill in Australia. It has now had a second stage extension added and the initial project is discussed by Parker and Sadlier (1991)

3.2 Other Projects

There are a number of landfill lining projects in planning stages in several different Australian States where synthetic liners are an important part of the overall strategy. These include the Brisbane City Council waste disposal project where several of the tenderers proposed HDPE liners. The successful Rochedale Landfill proposal included a synthetic leachate collection system and a 1.5 mm HDPE liner over a 0.9 m compacted clay liner.

Engineered clay liners are still used on occasions such as the Lyndhurst (Vic) landfill which took advantage of good quality clay at site.

4.0 LANDFILL CAPS

In the case of many existing landfills and waste dumps their potential to pollute may be effectively curtailed by the provision of an effective cap to control water ingress and gas escape. Closure liners with gas collection and drainage are often an integral part of the design of new waste disposal facilities.

Landfill closures often require a somewhat different set of properties for synthetic liners than do landfill bottom liner installations. In particular, cap design usually presents the geotechnical engineer with greater concern regarding long term slope stability and accommodation of differential settlement. Friction between synthetic liners and materials contacting those liners, multiaxial elongation, and flexibility become more important for covers. And because leachate does not contact the liners and there is limited UV exposure, chemical resistance and UV exposure resistance become less important. Resistance to the components of landfill gas is, in many cases, all that is necessary.

As a result, synthetic liners with a textured surface to improve friction angles, and Very Low Density Polyethylene (VLDPE) geomembranes are becoming very attractive to geotechnical engineers. They provide considerable improvement in those areas which are important for cap installation. These materials, however, behave differently in standard index and performance testing of geomembranes, when compared with traditional polyethylene liners.

Because of their elasticity, geomembranes can accommodate shifting in the closure subgrade without losing their barrier performance. Standard clay caps, on the other hand, can lose a great deal of barrier performance due to their absence of elasticity and the consequent development of cracks and fissures. Clay caps can also experience difficulties with variable compaction, moisture variation, and root growth.

Having no interconnected pore structure, geomembranes have no true permeability since permeability coefficients depend on Darcy's Law, a correlation for laminar flow in porous media. What little movement takes place through geomembranes is by diffusion. For water, diffusion through polyethylene is roughly a million times less than the permeability through a well compacted clay. With no effective permeability, synthetic liners thus provide excellent protection against both rainfall penetration into the closure, as well as landfill gas escaping from the closure. Good containment of landfill gas means that gas collection becomes more interesting and that vegetative covers for the closure grow much better since the gas does not contaminate the roots of the vegetation. This enhances slope stability even further and provides better erosion control for the final closure.

4.1 Very Low Density Polyethylene (VLDPE) Liners

Very Low Density Polyethylene (VLDPE) is a modern grade of polyethylene which takes advantage of the catalyst and copolymerisation manufacturing techniques of the pipe grade polyethylene's to produce a final polyethylene product of very low density. VLDPE combines many of the durability features of HDPE membranes, e.g. lack of plasticisers, low temperature resistance, carbon black stabilisation to UV light, good strength without the need for fabric reinforcement, resistance to microorganisms, insects and rodents, etc. VLDPE also has excellent natural flexibility, which is inherent, and not the result of plasticisers as is the case with most other very flexible membranes. Stress crack resistance is also excellent. And VLDPE gives good results in truncated cone puncture and multiaxial elongation tests as well. It's promise as a very durable liner for final cover of landfills is substantial.

Figure 1 shows results from tensile testing of HDPE and VLDPE liners in both smooth surface and textured form.

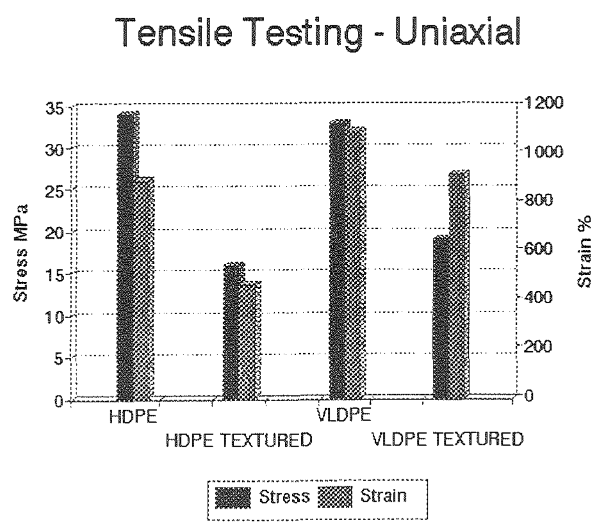

FIGURE 1.

VLDPE is also available as a textured surface geomembrane. In textured form, VLDPE combines its durability, flexibility and elongation with quite improved friction properties in contact with many different boundary materials.

4.2 Textured Polyethylene Liners

Some of the hazards that arise from the very low interface friction angle of typical smooth surface synthetic liners are discussed by Hausmann, Sadlier and Beckingsale (1992). Textured surfaces for synthetic liners have been developed in response to provide a capability for more stable interfaces.

Most textured HDPE sheet is currently made by 3-layer coextrusion, mingling the molten polyethylene in the outside textured layers with the inside smooth layer. Since the mixing occurs in the molten phase, the textured surface is fully integrated with the inside layer, which acts as the barrier to waste migration. The textured surface therefore resists abrasion and is not loosened by chemical absorption, nor physically scraped off as can happen with spray-on types of textured surfaces.

Figure 2 displays typical improvements in friction angles by direct shear for coextruded textured high density polyethylene (HDPE) liners. The friction angles indicated are approximate and will vary depending on test set up, apparatus and materials. For design purposes, actual site materials should be tested.

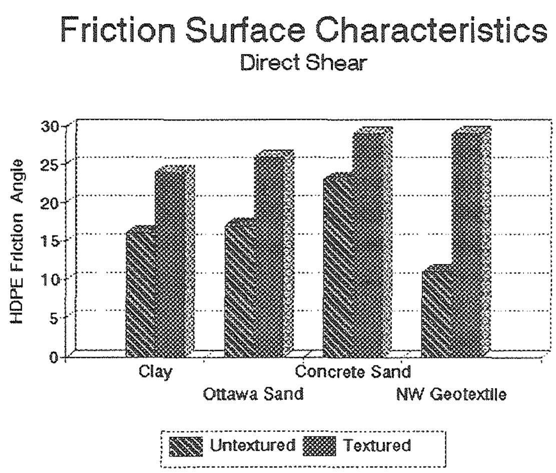

FIGURE 2.

4.3 Multiaxial Testing

Texturing of the outside layers sets up a wavy interfacial zone between outside and inside layers of the sheet which can cause edge-effects in a narrow (typically 6 mm for ASTM D 638) tensile specimen. These edge effects act as stress concentrating notches to reduce apparent tensile break performance in standard uniaxial tensile testing of textured sheet.

Recognition of this shortcoming is one reason for the development of a test procedure to examine multiaxial tension and elongation performance. This procedure is basically a large scale burst test which delivers tension to a liner sample in 360 degrees, instead of a uniaxial one-dimensional direction. A commonly used test method for multiaxial elongation is GRI GM4. (GRI is the Geosynthetics Research Institute, Philadelphia, USA.)

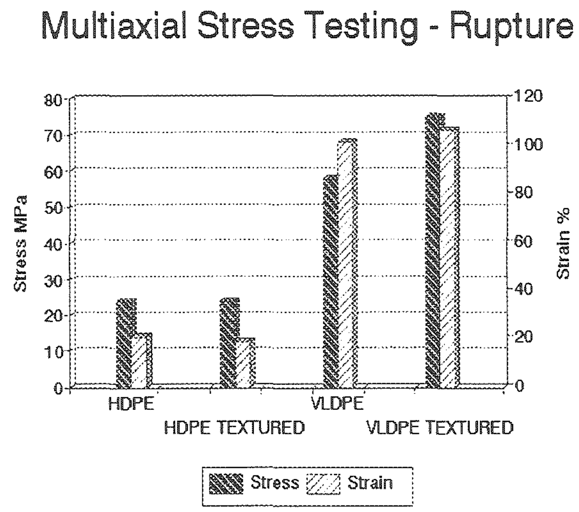

FIGURE 3.

Figure 3 compares performance of textured HDPE and VLDPE to standard smooth HDPE and VLDPE in multiaxial elongation testing.

The beauty of multiaxial elongation testing is that it eliminates edge-effects present in uniaxial tensile testing. There are simply no edges in the test sample to influence results when correlating them to the large scales in the field. For this reason as well as for the fact that tension forces in the field are very often multiaxial, multiaxial elongation testing is considered a "performance" test, more suitable for design purposes than the uniaxial tensile test.

Because edge-effect bias is eliminated, the multiaxial elongation test offers a better test to evaluate true performance of textured liners.

4.4 Gosnells Landfill Cap

This facility is in the City of Gosnells near Perth W.A. and it started life as a industrial liquid waste collection pit and has since been topped up with domestic waste prior to the installation of a HDPE and soil composite cover. Details are discussed by Parker and Sadlier (1991).

Another interesting capping application is the Kingston (Brisbane) contaminated site clean-up which used a geosynthetic liner system as part of a composite capping strategy for the more severely contaminated area. This capping project is discussed in detail by Sadlier, Fehervary and Marsh (1992)

5.0 GEOTEXTILE USE WITH SYNTHETIC LINERS

There are numerous potential applications of geotextile fabrics with geomembranes due mainly to their polymeric compatibility and the filtration, drainage and mechanical protection capabilities of the geotextiles. Common uses include filter protection of drainage layers, friction control at interfaces, temporary covering, puncture protection and fluid transmission. The last two are discussed here.

5.1 Geomembrane Puncture Protection

Impermeable geomembrane liners used in containment systems are relatively thin and can be damaged easily, both during installation of the liner system as well as after completion of construction due to loads imparted by waste and other cover materials. Experience has shown that needlepunched nonwoven geotextiles can play an important role in successful geomembrane installations and long term performance by acting as a cushion to prevent puncture damage to the geomembrane.

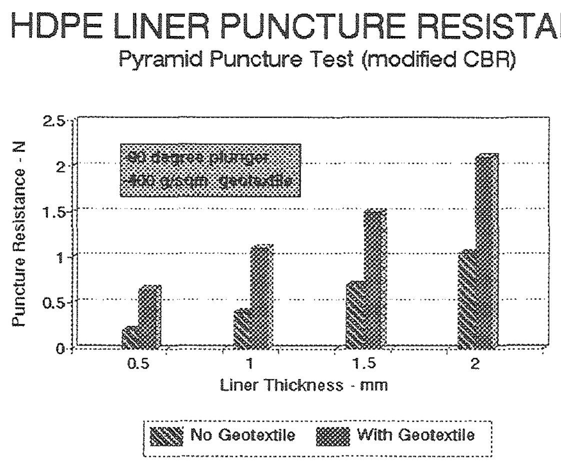

FIGURE 4.

Geotextiles can be placed below geomembranes to resist puncture and wear due to abrasion caused by sharp edged rocks in the subgrade and above the geomembrane to resist puncture by drainage aggregate, waste materials or other solids. Similarly, during intermittent covers and final closures, geotextiles can be placed below the geomembrane to reduce risk of damage by sharp objects in landfills and above the geomembrane to prevent damage during installation of soil cover. In order to provide sufficient protection against puncturing of a thin membrane, only those types of thick needlepunched nonwoven geotextiles with more than 200 g/sqm weight per unit area are recommended.

Results from testing carried out by Puhringer are illustrated in Figure 4. The procedure employed a 90° included angle pyramid plunger in a CBR rig with a metal plate under the geomembrane. Various thicknesses of HDPE were tested with and without different grades of non-woven continuous filament polypropylene geotextile. In this illustration the geotextile has a unit mass of 400 g/sqm and it is interesting to note that the effective puncture resistance of a 2mm liner can be provided by a 1mm liner and geotextile at considerable cost saving.

5.2 Liquid and Air Transmission

Relatively thick needle punched nonwoven geotextiles have a three dimensional fibre structure and high percentage of air voids which allows radial free flow of liquids and gases in the plane of the fabric. As such, they can be used as a drainage layer in the following situations which are presented as examples:

- Between the two membranes of a double lining system, in order to drain any leakage that may occur through the primary (top) liner.
- Between membrane and soil, or between membrane and waste material to drain any slope, waste seepage or groundwater. (Moisture between a geomembrane and underlying soil can significantly decrease the interface friction angle.)
- Beneath a geomembrane liner in a liquid containment system to divert gases from beneath the system that can accumulate due to organics in the underlying soils.
- Beneath intermittent and final landfill cover systems over waste disposals to act as gas transmission media and divert gases to collection systems.

5.2.1 Water Transmission

Design and selection of the geotextile will depend on the magnitude of anticipated seepage, the normal stress anticipated over the geotextile, and the geotextile characteristics including thickness, weight per unit area, and fibre type. Different fibre shapes, needling lubricants and fibre lengths can all affect the surface tension and flow characteristics so product specific tests are essential. Transmissivity responses of needlepunched nonwoven geotextiles as a function of normal stress are readily available and calculations based on Darcy's formula can be used to determine if flow capacity is sufficient.

In many cases the anticipated flows are not large and are difficult to quantify with confidence but control is still critical. Evaluation of suitability is often based on order of magnitude correlations.

If greater transmissivity is required than can be provided by heavyweight needlepunched nonwoven geotextiles, special layered systems such as geonets must be installed.

5.2.2 Gas Transport

In this application, the same design considerations and calculation methods as for water transmission can be used. Because of the high porosity of needlepunched nonwoven geotextiles (90% air voids in an uncompressed state), gas transmissivity is usually sufficient, even under very high applied normal loading. Under comparable conditions, gas transmissivity is approximately two orders of magnitude greater than water transmissivity (Koerner, et al., 1984). Therefore, it is sufficient to base the design on water transmissivity, since even with a high water content in the geotextile there will be sufficient gas transmissivity available for the venting of gases.

6.0 LIQUID STORAGE LINERS AND COVERS

Synthetic liners are well known in liquid containment around Australia and in Asia but there is potential to make better use of synthetic covers for protection of water supplies from pollution and evaporation losses.

Golf courses and similar developments have made use of thin PVC liners for water containment and this choice has been made on the basis of minimising capital cost at the expense of service life unless a soil cover is also used. Dissatisfaction with long term performance of PVC liners in such pondages has resulted in a trend towards thin HDPE and VLDPE liners which are cost effective and offer better exposure performance.

Reservoir floating covers in synthetic liner material provide the potential to control pollution (e.g. from birds) and evaporation losses at a significant cost advantage over conventional roofing. If the water level is to fluctuate constantly then a liner material with excellent flexibility is required but this can be in conflict with the other requirements of excellent UV weathering performance and weldability even after exposure. A rational approach to this problem is to use different combinations of materials to maximise flexibility in unexposed portions and to maximise UV weathering performance in exposed portions.

7.0 ANAEROBIC LAGOONS

Anaerobic digestion is a very effective method for biological treatment of sewerage sludges and floating covers in HDPE can sustain anaerobic activity in large scale lagoons with odour control and methane gas collection as secondary benefits. This type of cover can be installed over existing aerobic lagoons to give the twin benefits of anaerobic digestion and odour control. Many industrial complexes find this concept attractive as do municipal sewerage authorities considering the implications of urban sprawl taking built-up areas closer to existing aerobic lagoons.

Normally there is very little fluctuation in level in these lagoons and the gas is collected under a vacuum so that chemical resistance, UV weathering performance, and weldability are at a premium over flexibility, making HDPE the normal choice of cover material. The cover is usually attached to a concrete edge anchor beam or restrained by a backfilled anchor trench and HDPE pipes are used for the gas connections. Floating end details are also possible and this allows the possibility of partial covering of existing lagoons.

There are several smaller examples of this use of a synthetic liner digester lagoon cover around Australia including digesters for food processing plants at Manjimup in W.A. and Bendigo in Victoria. Very recently Melbourne Water have installed the world's largest floating HDPE membrane digester cover over an active anaerobic pot at their Werribee Sewerage Farm.

An indication of the potential of the concept is the Sonoco paper mill digester in South Carolina USA which measures 290 m by 120 m (35,000 sqm) and is made from 2.5 mm HDPE. It removes 60-80% of the effluent BOD and produces approximately 10 cu.m/min. of bio-gas of which over 50% is methane which is used for its heating value.

8.0 CONCLUSIONS

Synthetic membrane liners have been seen in various applications around the Asia Pacific Region and most senior engineering practitioners will have had at least some passing experience with them.

With the increasing demand from the community for control of leachate formation and possible escape from waste disposal facilities there will be many opportunities to use synthetic liners to help protect our environment. There will also be opportunities for applications in water storage and particularly interesting possibilities in floating covers for digester lagoons for effluent water treatment.

As with many newer materials, success will come from recognition of the attributes and shortcomings of synthetic liners and employing them within their capabilities with appropriate quality control and checking measures.

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Landfill of Aluminium Smelter Waste at Wallaroo, NSW, Australia

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SYNOPSIS: Geotechnical investigations to assess the physical nature of the subsurface conditions, the geochemical properties of the soils and groundwater and the hydrogeological regime existing in an area proposed for the landfill disposal of Aluminium Smelter waste were undertaken to ensure safe and responsible management of this waste material was carried out.

The studies of the Wallaroo site have indicated the deeply weathered soil profile to have some useful characteristics for landfill disposal. The Permian rocks have been strongly and deeply weathered to a heavy clay that has a low permeability and the clay mineralogy has been established to have a significant adsorptive capacity for the waste chemistry.

A hydrogeologic model of the site was prepared using finite element computer techniques and correlated using monitored response from piezometers installed within some 90 boreholes drilled to evaluate the site. The groundwater level response and its sensitivity to variable infiltration rates and permeability parameters was then predicted using various model rainfall events.

Based upon the investigation data and the modelling results, a proposed "Waste Disposal Area" was selected. Two trial pits were constructed in this area, using sand to simulate the waste material. The area of these trial pits was extensively instrumented to assess rainfall infiltration to the pits and surrounding ground. The area was then subjected to extremely high simulated rainfall, using a spray irrigation system, and the performance assessed.

The effects of leachable fluoride and sodium and the high pH on the acidic clay have been studied in batch tests and distribution coefficients and maximum adsorption capacities measured. High concentrations of sodium and fluoride have also been passed through compacted clay core to study the effects on permeability and a decrease in permeability has been observed.

Following these extensive studies approval was granted for the disposal of wastes in the landfill on the basis of the inherent favourable geotechnical properties of the site together with the various safeguards provided by on-going monitoring and the favourable chemical interaction of the leachate with the surrounding natural clay. Initial disposal campaigns have now been conducted successfully.

1 INTRODUCTION

Potlining waste, the major waste from the aluminium smelting process has significant levels of leachable fluoride, cyanide and sodium and has a high pH. At the present time and into the foreseeable future there are major difficulties in treating this waste in an environmentally satisfactory way to remove the problem components.

In Australia the current practise at established smelters is to either store the waste above the ground, with collection and treatment of leachate, or landfill disposal of the waste. Similar waste management methods are used in USA.

A new smelter operated by Tomago Aluminium Company commenced production in September 1983 at Tomago which is situated 160 km north of Sydney. The smelter produces some 200,000 tonnes of aluminium a year and will produce about 10,000 tonnes per year of solid waste.

During the period 1983 to 1986 a detailed geotechnical investigation was carried out over a selected potential waste disposal site some 20 km north east of the smelter at Wallaroo. The location of the proposed waste disposal site is shown on Figure 1. The investigation techniques adopted were as follows:

- Terrain Evaluation, Regional Geology and
- Surface Hydrology studies
- Drilling of boreholes, soil sampling, installation of piezometers, field permeability testing and monitoring of groundwater levels
- Hydrogeologic modelling
- Soil structure and soil chemical analysis
- Trial disposal pit construction and monitoring

An area of some 200 ha was initially assessed and an area of 50 ha selected for detailed study. An area of about 0.5 ha per year is required for landfill disposal for a 3 m deep thickness of waste.

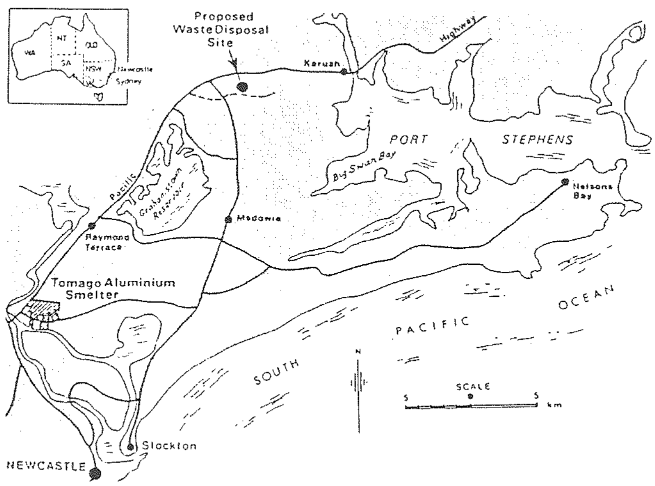

Figure 1 - Location of Landfill Site

2 TERRAIN, GEOLOGY AND HYDROLOGY

The proposed disposal area is situated on a flat to gently sloping topographic divide between the Port Stephens Estuary to the east and Grahamstown Reservoir to the south-west. The Estuary contains extensive commercial oyster leases and the Reservoir is a town water supply. The land is covered by a dry sclerophyll (open woodland) Eucalypt forest.

Beneath the forest there is a deeply weathered lateritic clayey profile developed on interbedded Permian siltstones, mudstones and clayey conglomerate beds to a depth of 20 to 40 m. At depth below the weathering zone beneath the proposed disposal site, there are gravelly strata overlying jointed rhyolite and ignimbrite volcanics.

Deep Tertiary lateritic weathering profiles are common in Australia and the age of major rock alteration has been dated elsewhere - Senior and Mabbutt (1979) as being mainly either Oligocene to Miocene (40-20 million years ago) when the climate was wetter than present. The weathering has chemically altered the rocks to aluminium and iron rich clay materials over depths of 20 to 30 m in a trough-like pattern that probably relates to a former Tertiary ground surface (Figure 2). This surface has undergone some change (erosion and deposition) in more recent times - Knight (1988).

3 SOIL CHARACTERISTICS

Over 90 boreholes and several test pits have revealed the soil characteristics. The acidic (pH 5.5) soils range from silty loams (slope deposit) to medium to high plasticity clays (in situ weathered rock) extending to 20 to 40 m depth with local zones of sandy and gravelly clays. Typical lateritic weathering patterns are present with reddish soils overlying a mottled zone passing down into a pallid zone and then to yellowish clays. The clays have a liquid limit ranging from 40 to 90 and plasticity index of 25 to 60. Natural moisture content is generally less than the plastic limit even below the water table confirming the highly overconsolidated nature of the clays. In situ permeability determined by insitu testing at some 50 locations indicated a mean value of 5×10^{-7} m/sec and ranged from 10^{-10} to 10^{-6} m/sec. A gravelly layer was found to exist 20 to 30 m below existing ground surface. permeability testing of this layer gave variable results the most permeable being 10^{-5} m/sec.

The clay composition is predominantly silica, aluminium and iron with lesser amounts of titanium, magnesium and potassium. Calcium is absent and sodium is very low which is typical of an extensively weathered and leached acidic profile of clay with low-cation exchange capacity.

4 HYDROGEOLOGIC REGIME

Monitoring of water levels within piezometer installations carried out during the early stages of the investigation revealed that groundwater levels beneath the south western (higher elevation) part of the site were quite sensitive to significant, but not abnormal, rainfall whereas the remaining area revealed quite minor response to natural rainfall.

This observation instigated a soil structure study of the upper 2 to 3 m of the soil horizon in the two areas which, in the responsive area, revealed the presence of vertical iron-rich tubular nodules down to 3 m which appeared vertically continuous and quite highly permeable and would allow the rapid passage of rainfall infiltration into the soil profile.

By comparison the soil structure in the less responsive area had a lesser proportion of iron-rich nodules with little apparent continuity.

The latter stages of investigation concentrated on the area which had relatively minor response to natural rainfall events. The phreatic surface in this area was generally 15 to 20 m below ground surface.

The piezometric surface within the underlying gravelly layer is quite insensitive to seasonal rainfall variation and has a very gentle hydraulic gradient down towards the north east.

4.1 Groundwater Modelling Study

A groundwater modelling study was carried out using Golder Associates suite of finite element groundwater programs to relate the properties of the soil profile to the observed patterns of groundwater response to rainfall. Initially a simplified vertical flow analysis was carried out to correlate the monitored response with inflow being a function of infiltration characteristics, permeability and storage coefficients. Outflow occurred via the underlying gravelly stratum.

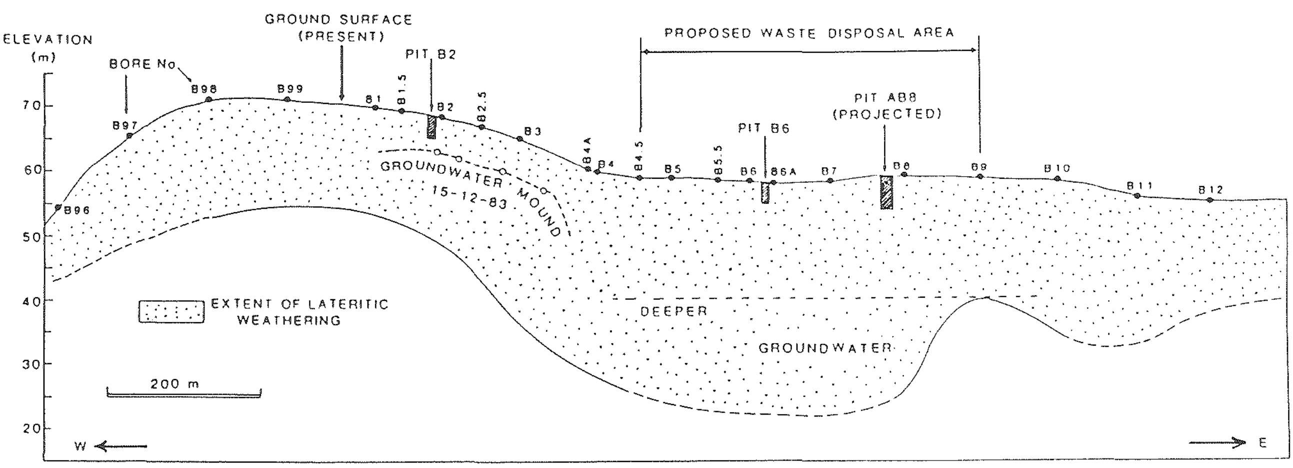

Figure 2 - East-West cross section through proposed Wallaroo waste disposal area showing lateritic weathering, groundwater, borehole and pit locations

A two dimensional analysis was then carried out modelling the observed water levels and recorded rainfall over a 9 month period with the infiltration factors determined earlier. After several trials a set of parameters were evolved which closely matched the observed data.

The calibrated model was then used to predict groundwater levels resulting from very heavy and very low seasonal rainfall situations. The infiltration characteristics were also varied to simulate the development of the site for its proposed waste disposal activity.

The modelling study was successful in mathematically assessing the sensitivity of the site to the effects of heavy rainfall however a more practical demonstration was considered appropriate to confirm the physical suitability of the site for waste disposal. Thus two substantial trial disposal pits were constructed.

5 TRIAL DISPOSAL PIT CONSTRUCTION

Two trial pits were excavated to a depth of about 5 m using large earthmoving plant. Pit A was excavated some 50 m long and 4 m wide with a central gently graded zone 10 m long and steeply graded access ramps at each end. The base of the pit had a 0.5 m thick local clay seal placed and compacted in thin layers. A 3 m thick layer of sand was placed over the central 10 m of the pit to simulate the waste and the ramp areas were built up with compacted clay. A clay surface seal 1.5 m thick was then placed over the simulated waste in thin layers each well compacted at slightly wet of optimum moisture content.

This trial pit was instrumented with piezometers and soil tensiometers at various depths within the upper clay seal, the simulated waste and the surrounding natural ground. Monitoring was then carried out at regular time intervals.

Following poor performance of Pit A under both natural and simulated rainfall, the upper clay seal was removed and extended at least 2 m beyond the plan extent of the simulated waste. Subsequently Pit B was constructed to a modified design which included a much wider excavation such that side walls of compacted clay were constructed to surround the waste. This pit was also comprehensively instrumented as shown on Figure 3.

5.1 Trial Pit Performance

A spray irrigation system was then installed to cover the areas of Test Pits A and B to provide a simulated rainfall. A rainfall intensity of at least 1.4 times the maximum weekly recorded rainfall for the area was applied over a period of two weeks. Regular monitoring of all piezometers and tensiometers was carried out during, and for several weeks following, the simulated rainfall event followed by periodic monitoring over a 12 month period.

The monitoring results indicate that rainfall very slowly infiltrates the upper 0.5 to 1 m of the upper clay capping; the tensiometers below 1.0 m indicating very minor moisture variation. No water entered Pit B however some water did enter Pit A and this was considered to have infiltrated the natural ground beyond the upper clay seal and then to have moved laterally towards the pit via microstructure and old tree roots within the natural clay and entered the walls of the pit. This microstructure was destroyed by the reworking of the clay in the walls of Pit B.

The satisfactory performance of Trial Pit B under the extreme rainfall events simulated was considered to demonstrate the effectiveness of an engineered clay capping. The comparison with the performance of Pit A indicates the necessity of compacted clay walls to ensure that no water can enter the waste material.

6 CHEMICAL BEHAVIOUR OF WALLAROO CLAY

The physical means of keeping water away from the waste, thus not generating leachate, were considered to be the primary means of managing the environmentally safe disposal of the waste.

As a secondary backup, should leachate be formed the chemical interactive behaviour of the leachate with the Wallaroo clay was also investigated. Detailed research findings have been discussed by Knight (1988).

6.1 Chemical Interaction Characteristics

The high level ground waters have very low salinity (100-200 mg/l) in equilibrium with kaolinite but salinity rises to 500 mg/l in the deeper clays where montmorillonite becomes significant and increases to

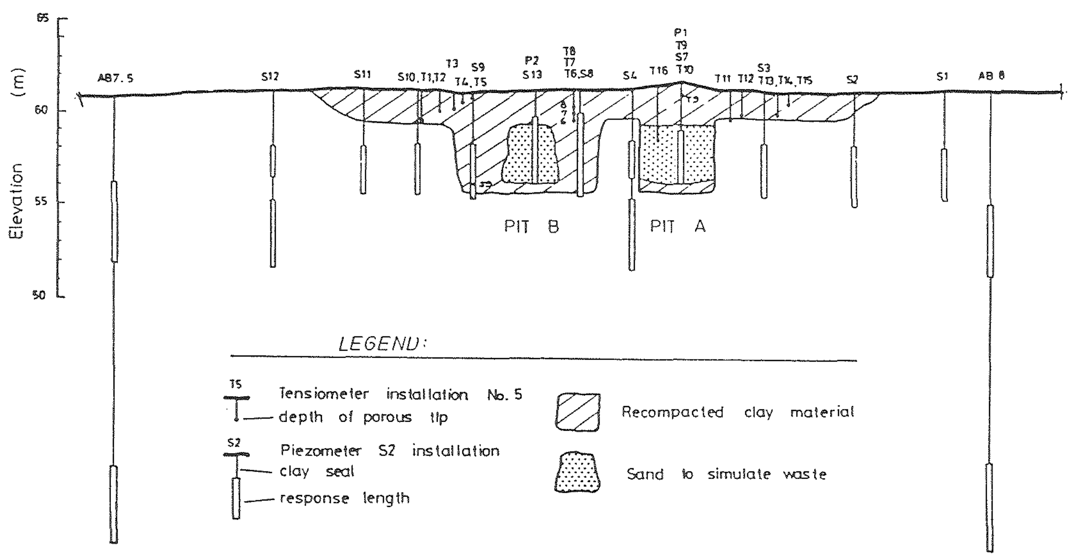

Figure 3 - Cross section through trial waste disposal pits showing pit geometry and instrumentation

1,600 mg/l in the underlying volcanics. Sodium and chloride are the dominant ions but are low (30, 60 mg/l respectively) in the upper 15 m leached zone, then increase with depth to 120 mg/l Na^+ and 250 mg/l Cl^-. If sodium should disperse from the disposal cells (5 m deep), it would be easily detected due to its low natural concentration in both groundwater and clay.

The acidic pH range of the waters (4-6) in the clays will have a significant buffering effect on any alkaline leachate (pH 12) formed from the waste.

6.2 Fluoride Adsorption

In order to simulate a fluoride leachate-clay interaction situation as closely as possible, batch tests using Wallaroo clay and sodium fluoride solutions were carried out within pH ranges (7-7.5 and 5-5.5), 4 concentrations of F (1 to 1,000 mg/l) with the soil solution ratio set at 2:1 and equilibriated over 10 days at 20°C. Polyethylene reaction vessels were hand shaken for 5 minutes each day and contrifuged to separate solid and liquid phases.

The variations in fluoride adsorption with time, pH and concentration fitted the Freundlich linear isotherm model and distribution coefficients (kd) were determined to be 3.3 ml/g (pH 7-7.5) and 3.1 ml/g (pH 5-5.5).

Other conclusions that may be drawn from this testing are:

- Most adsorption took place in 24 hours and by 10 days one could be confident that equilibrium had been achieved.
- An alkaline starting pH of 7-7.5 appears to result in equal or marginally better adsorption than the acid range 5-5.5
- Adsorption increases with concentration of F and at day 10, ranges from 1.7 mg F^-/Kg clay for 1 mg/l F solution to 2968 mg F^-/Kg clay for solutions with 1000 mg/l F^-.

Distribution coefficients from batch tests were used to estimate likely retardation factors that could be applied to vertically migrating fluoride fronts. An analysis using the proposed disposal design and soil properties suggested that 14 may be a reasonable retardation factor to apply to vertical flow velocities. In addition the maximum adsorption capacity was found to be useful in the evaluation of the site's ability to realistically adsorb the expected leachable fluoride.

6.3 Leachate effect on Permeability

A compacted core of Wallaroo clay was installed in a modified pressure chamber of a rock permeameter. The permeameter was initially filled with deionized water to establish stable baseline permeability. The deionized water was then replaced with NaF water at a concentration of 834 mg/l F and 1,020 mg/l Na^+. The pH of the solution was 6.3 and Eh + 208 mv. As the water discharged from the core it displaced an immiscible light oil up a burette which enabled discharge rates to be measured. Leachate samples were periodically pipetted from below the oil water interface. Fluoride content and sodium concentrations, Eh and pH were measured.

Permeability decreased with time by almost an order of magnitude over the 20 days of the test from 1.4 x 10^{-8} m/sec to 2.4 x 10^{-9} m/s at the end. The decrease appeared to be directly due to the Na interacting with the clay. The reduction in permeability is presented shown graphically on Figure 4.

The effect of NaF water on consolidation was examined using another sample of the clay in a standard consolidometer. Rigid filter ends and a static load of 100 kPa were used. The clay was compacted dry and presaturated with deionized water. A sharp decrease in void-ratio was observed when the NaF water was added to the clay that had achieved a stable consolidation using deionized water.

Consolidation in the field situation could occur where voids with pore pressures relatively lower than Na induced osmotic pressures did not exist and the effective overburden pressures are larger than the generated swelling pressures.

Though permeabilities of the consolidating clay were not measured, it seems reasonable that they would reduce during the process.

6.4 Retardation effects of NaF adsorption

Analysis of the sodium and fluoride break- through curves indicate that if the distribution coefficient (Kd) for fluoride determined in the clay core (1.91 ml/gm) was applied to a vertically migrating front at Wallaroo the flow velocity retardation factor is more likely to be 9 rather than the 14 estimated from the batch tests. The Na and F breakthrough curves are also presented on Figure 4.

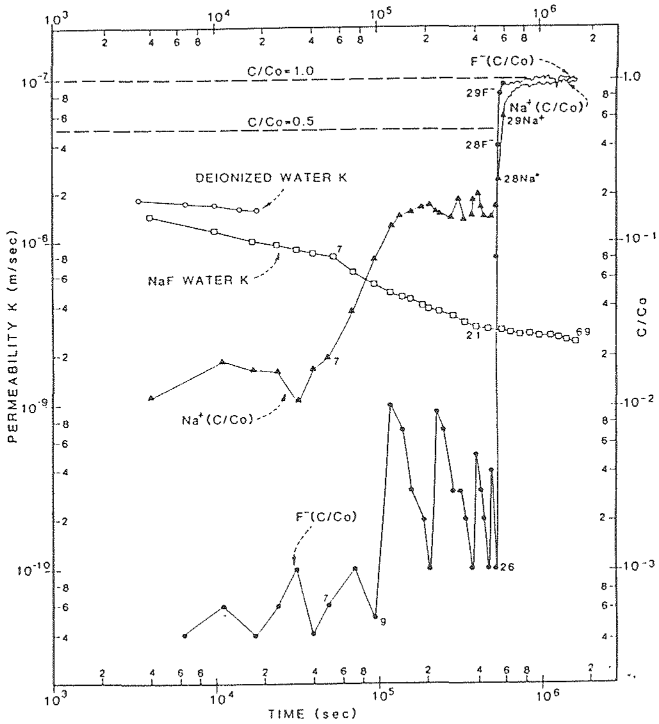

Figure 4 - Permeability (K) and sodium and fluoride relative concentrations of outflow with time - Knight (1988)

6.5 Spent Potliner Leachate - Clay reactivity

Samples of crushed potlining waste were used to form a leachate for clay reactivity studies. Some 25 g of the waste components were mixed in their approximate proportions found in a typical waste stream.

The 25 g of waste mix were added to 50 ml of deionized water and reacted over 6 days. Both hand and tumble shaking were used. Leachate is variable but is typically high in sodium, aluminium fluoride and iron and was extremely alkaline and reducing.

Leachate was reacted (shaken) with the clay in the proportions 5 g clay to 15 ml fluid over a 4-day period and then allowed to stand for 3 months. The reaction vessels were sealed in polyethylene tubes.

Dried leachate reacted clay and clay that had been in contact with deionized water were X-rayed at the end of the 3 month reaction time. The XRD traces show that a new mineral phase has formed. It is considered that the mineral is a type of sodium aluminium silicate possibly of the zeolite family.

6.6 Summary of Chemical Aspects

Based upon the chemical testing programme carried out it is considered likely that should aluminium potlining leachate be formed and leak into the natural clay formation it will cause a decrease in permeability of the kaolinitic lateritised clay by at least an order of magnitude as a result of sodium-clay dispersion and increases in expansive osmotic pressures. Additional consolidation occurring following dispersion is also likely to cause a permeability decline. Further decreases in permeability can be expected due to the formation in pore spaces of a new mineral phase arising from reactions between leachate and the clay.

Fluoride and sodium adsorption characteristics of Wallaroo clay are similar to each other and significant retardation of contaminant flow velocity has been forecast.

7 WASTE MANAGEMENT STRATEGY

7.1 Suitability of the Site

Based upon the detailed subsurface information available concerning the subsurface stratigraphy, permeability and groundwater levels, a suitable area of some 15 ha was selected for the buried waste disposal activity. This site has several natural security measures for waste disposal:

The primary attributes of the site are as follows:

- The area has an extensive deposit of clay soil extending 20 to 25 m depth overlying a more permeable gravelly stratum. The groundwater table within the clay profile, and the piezometric surface within the underlying gravelly layer, have been monitored for a period of 3 years and observed not to vary greatly in response to variable rainfall and to remain at least 15 m below the existing ground surface.

- Modelling using computer mathematical techniques indicated the groundwater level to remain at least 15 m below the surface in response to very heavy (extremely low frequency return) rainfall events.

- The permeability of the clay soils was determined at depth using field testing techniques to be very low with a mean value of 5×10^{-7} m/sec.

- The clay materials which would become available from disposal pit excavation are considered to be most appropriate to provide the necessary upper clay capping.

In addition the following chemical attributes are available as a secondary backup should leachate be formed in the pit.

- The natural clays' high potential to adsorb both sodium and fluoride. In addition the chemical reactions which take place are indicated to further reduce the permeability of the natural clay.

- The retardation factors in the passage of sodium fluoride through the clay which would result in any contaminant front moving at about one ninth the velocity of the leachate front.

The natural properties of the site should however be further enhanced by appropriate landfill waste disposal methodology.

7.2 Landfill Disposal

Engineered compacted clay covers over waste materials have generally only been partially successful as they tend to leak to some degree based upon North American and European performance evaluation. The two main reasons for this are considered to be:

Firstly clay covers are commonly quite thin (less than 1 m) and are quite susceptible to desiccation cracking, freeze - thaw and thermal expansion effects; the latter effects being major considerations in North America and Europe where most performance studies have been carried out, but of little relevance for the Wallaroo site which has a temperate climate.

Secondly the underlying waste materials are normally placed without good compaction and subsequent settlement causes fracturing of the capping layer. In addition, for putrescible waste facilities the build up of gas pressures can cause rupturing of the overlying clay cap.

In view of the poor performance of natural clay cappings (due to the above factors) in North America and Europe the trend in these countries is now towards the use of synthetic materials placed as a layer within a multi layer capping. This trend is now enforced by legislation in some countries, particularly the United States where standard designs incorporating synthetic liners are required above and beneath all hazardous waste disposal landfills.

Synthetic liners may also have deficiencies both in their purported fabric impermeability and also due to difficulties with installation - Haxo (1981).

The two main reasons for the non performance of natural clay capping in North America and European environments and experiences are not considered to be particularly relevant to the design of the Wallaroo Facility because:

- a thick clay cover is proposed, the upper 0.5 m or so being considered sacrificial to the unavoidable desiccation which will occur.

- The site is not subjected to freeze/thaw conditions.

- The waste for disposal at this site is not putrescible and it is proposed to thoroughly compact the waste material so that no subsequent settlement will occur, hence no cracking.

Based upon the above arguments the use of a thick engineered clay cover and base was considered appropriate for the Wallaroo Facility.

7.3 Legislative Requirements

New South Wales State Government Legislation to control chemical wastes was initiated in 1985 with the introduction of the Environmentally Hazardous Chemicals Act, 1985.

In accordance with this Act the State Pollution Control Commission (SPCC) of NSW issued a "Chemical Control Order in Relation to Aluminium Smelter Wastes Containing Fluoride and/or Cyanide" which prohibits the disposal of wastes containing leachable fluoride and/or cyanide; the definition of "leachable" being in the case of fluoride a leachate containing more than 150 mg/l and for cyanide a leachate containing more than 5 mg/l according to SPCC approved test procedures.

The Control Order also requires that a licence be issued for the keeping, conveying and disposal of wastes which have a leachable component less than defined above.

Licenses were issued to Tomago Aluminium for the disposal of "Approved Smelter Waste" in December 1986. This waste was considered to be non-hazardous in accordance with the above definition. Cyanide bearing wastes were excluded from the landfill disposal. The fluoride waste included meets the leachate criteria stated above.

7.4 Disposal Pit Design

The size selected for each pit is a function of the amount of material requiring disposal within each particular disposal campaign. Each campaign was expected to vary from 3,000 to 10,000 tonnes. The depth of disposal pits was selected as 5 m with a base compacted clay seal of 1.0 m thickness.

During each disposal campaign the base of each cell is graded smoothly to one corner where a shallow depression (sump) is excavated; and a layer of sand and gravel placed in this depression which forms the base of a monitoring well drilled after completion of the pit.

The waste material which arrives by covered truck is tipped directly in to the cell, spread and compacted in lifts by a heavy roller to a depth of 3 m within the 4 m deep pit. The surface seal is then placed, using the excavated clay spread in layers of about 200 mm and compacted to finally achieve about a 2 m thickness; the final ground surface being about 1 m higher than original, mounded to promote surface runoff then topsoiled and revegetated with shallow rooted species.

Upon completion of each cell a bore is drilled at the plan location of the previously excavated sump and a slotted PVC pipe installed through the waste. This installation will be used for detection of any leachate and which can be used for extraction should it be necessary.

A surface interceptor drainage system installed by grading shallow dish drains between each cell further minimizes the potential for infiltration through the clayey soil cover.

7.5 Monitoring Programme

An ongoing monitoring programme is part of the management strategy. This programme involves periodic water level measurement and sampling of installations within the natural clay formation in the vicinity of the waste disposal area. In addition the wells installed within each waste pit are regularly monitored for leachate. No problems have been experienced over the operational period (1986 to date).

8 CONCLUSION

The comprehensive geotechnical investigation programme carried out has provided the basis for convincing the regulatory authorities that the various natural attributes of the site together with an environmentally sound waste disposal procedure enable a natural clay site to be used for landfill disposal of most of the waste material from the Tomago Aluminium Smelter.

On-going monitoring will continue to ensure that the landfill does not adversely affect the surrounding environment.

ACKNOWLEDGEMENTS

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The assistance provided by the staff of Golder Associates Pty Ltd Consulting Geotechnical Engineers in the performance of the field investigation component of the investigation work is gratefully acknowledged.

We also wish to thank many of the people at the School of Applied Geology at the University of NSW for the chemical testing and peer review.

Data used in the paper has been drawn from unpublished reports over the period 1983 to 1986 by Golder Associates Pty Ltd and Knight M J.

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Co-Disposal of Coal Mine Tailings and Coarse Reject: A Promising New Technique

D.J.WILLIAMS[1]

ABSTRACT

The washing of Australian black coal produces coarse grained waste or coarse reject, and fine grained waste or tailings. Coarse reject is easily handled and is conventionally dumped in piles where it ravels at its angle of repose. Tailings, on the other hand, are difficult to handle and have conventionally been kept separate from the coarse reject and disposed of separately. Conventionally, thickened tailings are pumped as an aqueous slurry to a storage, where they remain in the form of a "wet" deposit. The rehabilitation problems associated with wet tailings have prompted a search for alternative disposal techniques. The technique of co-disposal by the combined pumping of the tailings and coarse reject is emerging as the favoured approach.

1. INTRODUCTION

Australia has major black coal mining operations in Queensland's Bowen Basin and in the Hunter Valley of New South Wales, with considerable potential for further development of these coal fields. The run-of-mine coal must be washed to meet export market specifications. Processing produces coarse grained waste (up to 100 mm in size, termed coarse reject), and fine grained waste (2 mm and finer, termed tailings). The coarse reject is easily handled and is conventionally loose dumped in piles, where it ravels at an angle of repose of about 37° to the horizontal. However, loose dumping of the coarse reject may lead to acid mine drainage problems and degradation of the material, and the dump slopes may have to be flattened to ensure stability and minimise erosion in the long term.

The tailings are difficult to handle and conventionally have been kept separate from the coarse reject and disposed of separately as an aqueous slurry. The resulting "wet" tailings deposits are difficult to rehabilitate and result in very limited potential for future land use. The recognition of the future environmental and economic liability of current coal mine waste disposal practices has brought about a hardening of the approach taken by the Regulatory Authorities. Over the last decade a number of alternative disposal techniques have been tried. However, they have not involved a fundamentally new approach, and have met with variable success. A promising new technique involves the co-disposal of coarse reject and tailings slurry by combined pumping to a storage. This cost-effective technique results in a mixture which has reasonable engineering properties and behaviour, and offers potential to facilitate rehabilitation and future land use to a high level, and limit any acid mine drainage.

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2. CURRENT APPROACH OF REGULATORY AUTHORITIES

The Regulatory Authorities in both Queensland and New South Wales require new coal mine projects to address the disposal and rehabilitation of washery wastes in their environmental management plan. The plan must subsequently be demonstrated by the mine, to the satisfaction of the Authority, to meet agreed environmental performance criteria. These relate to erosion and water contamination, both on the surface and below ground. Essentially, the mine should aim for negligible erosion of the surface of the rehabilitated landform, and negligible mine-induced contamination of surface or ground water. The extent to which the mine achieves its environmental performance criteria is rewarded by a partial refund of the security deposit which must be lodged with the Authority. The full security deposit is a realistic estimate of the full cost of rehabilitation, and for Queensland is typically in the range A$15 000 to A$25 000 per hectare. Existing coal mines will progressively, to the extent possible, be brought into line with the policy for new coal mines. A similar policy applies to all other mining developments.

The Authorities give little guidance as to how the performance criteria could be met, but expect the mine to consider all available approaches to washery waste disposal and rehabilitation, having due regard to the characteristics and behaviour of the materials involved, and to any peculiarities of the mine site and its location. The Authorities are reluctant to see the further proliferation of conventional wet tailings storages, which present rehabilitation difficulties, and there is increasing concern about the potential for acid mine drainage from coarse reject dumps.

In view of the tight criteria which must be met, by new coal mines in particular, washery waste disposal and rehabilitation must now be engineered to create an environmentally acceptable final landform at reasonable cost. To achieve this, the shape and surface treatment of the final landform must be decided in advance. To minimise cost, the shape formed by the deposited waste should ideally match, as closely as possible, that of the final landform, provided that the environmental performance criteria can be met.

Surface erosion is difficult to avoid on even very flat slopes if the exposed materials are highly erodable. Less erodable materials would allow surface vegetation to be established, which would mitigate against subsequent erosion. To minimise the erosion of susceptible materials, or of steep slopes, protection of the surface by sound rock beaching would be required. However, a source of sound rock would need to be readily available. If surface erosion can be controlled by a suitable capping of the waste, it is likely that the contamination of surface water can also be controlled. The control of ground water contamination depends on avoiding the seepage of contaminated water from the waste into the underlying ground.

The minimisation of oxidation of the mine waste materials is essential to the maintenance of acceptable water quality. Materials with a potential to form acids should be separated, selectively disposed of, and either isolated from atmospheric oxygen or treated. In the past, little attention was devoted to separating waste materials with a potential for generating acid mine drainage. In particular, material in coarse reject dumps which readily oxidises, can do so to the base of the dump, and in some cases can ignite, giving off noxious gases. By virtue of their fine grain size and high moisture content, tailings deposits comprising material which readily oxidises, will experience oxidation to only limited depth (the upper 15 cm, or so).

3. ECONOMIC IMPLICATIONS

It has been recognised that the future liability of past coal mine waste disposal practices in Australia, involving difficult to rehabilitate wet tailings deposits and potentially environmentally unacceptable coarse waste dumping, could force the premature closure of otherwise economically viable coal mines. Even without this future liability, conventional man-made tailings dams are expensive to construct, wet tailings deposits occupy large areas of land, and such deposits can be expensive to rehabilitate. Coal mine waste disposal and storage options must be developed which meet enhanced environmental standards aimed at ensuring sustainable mining development, while minimising the initial, ongoing maintenance, and future rehabilitation costs involved.

4. CURRENT DISPOSAL PRACTICES

Conventionally, the tailings are thickened and then pumped as an aqueous slurry at a solids concentration of about 30% by weight to a storage, where they form a "wet" deposit. The tailings undergo beaching, sedimentation, self-weight consolidation, and crusting if desiccation of the surface occurs. A delta with an average slope of only about 1 in 100 is formed, with some hydraulic sorting of particles taking place down the delta. With increasing distance down the delta from the highest point, (about 5 m beyond the discharge point) particles of finer grain size are deposited. Figure 1 shows this effect for the delta formed in the Main Tailings Dam at Aberdare Colliery in the Ipswich Coalfields. Also shown in Figure 1 is the input particle size distribution.

A secondary trend is for the specific gravity of deposited particles to decrease with increasing distance down the delta from the highest point (Figure 2). The deposit remains wet because of the fine grain size of the tailings and hence its low permeability, with a thin crust forming where desiccation can occur.

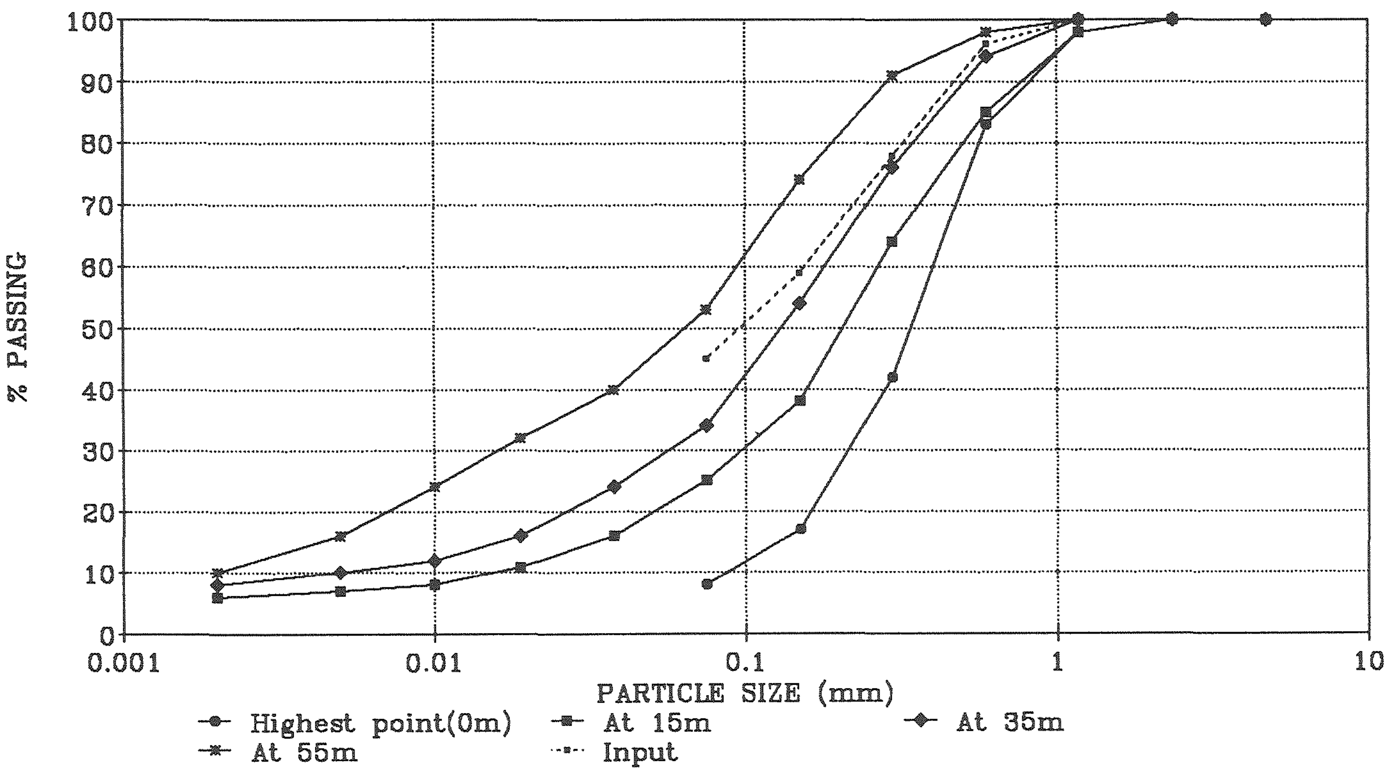

Figure 1 :Hydraulic sorting of particles with distance from highest point of Aberdare Colliery Main Tailings Dam delta, Ipswich Coalfields.

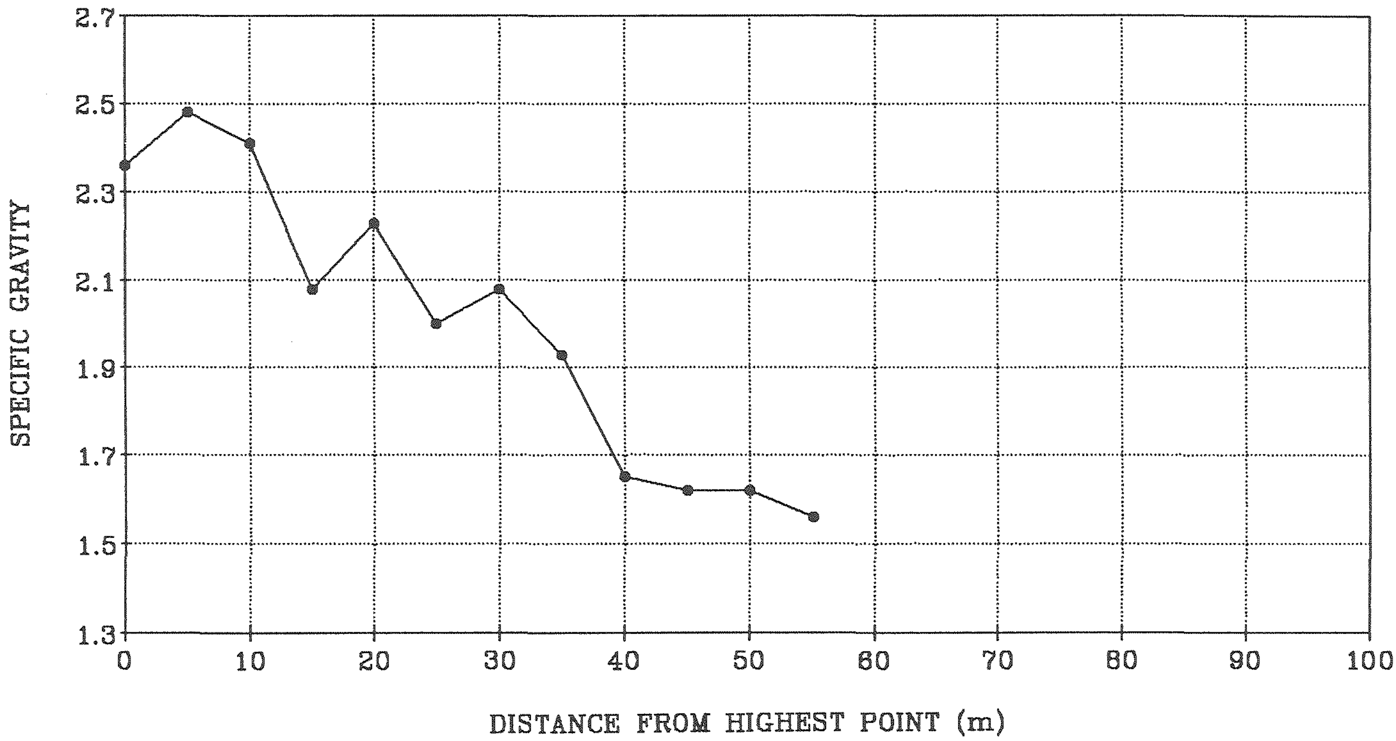

Figure 2:Variation of specific gravity with distance from highest point of Aberdare Colliery Main Tailings Dam delta.

The more sophisticated washeries are capable of separating coal down to about 60 m, while the old inefficient washeries may release as tailings the minus 2 mm size. Typically, coal mine tailings comprise 20 to 40% clay size (finer than 2 m) and 5 to 30% sand size (coarser than 60 m), with the remainder of silt size (2 to 60 m). The typical tailings particle size distribution may be described as sandy clayey silt, with about 70% silt and clay size. Tailings typically have a liquid limit in the range 30 to 45% and plasticity index in the range 10 to 25%, indicating a Unified Soil Classification of ML or CL. However, some tailings are non-plastic. The average specific gravity of coal mine tailings is typically in the range 1.7 to 1.8, compared with about 2.7 for mineral matter, indicating that up to 60% coal is present. The undrained shear strength of the tailings is typically about 10 kPa in the soft tailings at depth, with the surface crust of about three times that strength. The tailings have a drained angle of internal friction of about 30° in direct shear and about 28° in triaxial compression. The in situ permeability of the soft tailings at depth is typically of the order of 10^{-7} $m.s^{-1}$, one or two orders of magnitude higher than indicated by laboratory test results. Due to layering of the deposit, the horizontal permeability is about five times that in the vertical direction.

The problem of dewatering the wet tailings deposit is both relieved to some extent and exacerbated when the surface of the sediment becomes exposed and desiccates. While desiccation results in the formation of a relatively stiff surface crust, the crusting effect persists to only shallow depth, it is largely reversible on re-wetting, and it results in a surface layer of very low permeability despite the presence of desiccation cracks. The very low permeability of the crust (as much as three orders of magnitude lower than that of the underlying soft tailings), inhibits the further dewatering of the underlying tailings.

In response to wet tailings disposal becoming less acceptable, the Australian coal mining industry, notably in New South Wales, initially turned to the mechanical dewatering of the thickened tailings. Centrifuges were first used for this purpose. These achieved a substantial increase in the solids concentration of the tailings. However, the consistency produced was not amenable to transportation by conveyor or truck, nor to pumping. Belt press filters have been used with greater success. They can produce a filter cake capable of transportation by conveyor or truck, and the feed may readily be combined with the coarse reject in dumps. Mechanical dewatering carries a number of technical problems, among them allowing for the variable input feed, assessing the potential for and the consequences of the filter cake re-wetting in the dump, flattening the dump slope to an angle acceptable in the long term, and the choice of an appropriate surface treatment. However, also working against mechanical dewatering is that it is extremely expensive, particularly in flocculants. The cost of the flocculant required can amount to $1 to 2 per tonne of coal produced, depending on the proportion of tailings.

Another approach has been to dispose of tailings slurry within the valleys formed between successive overburden (spoil) piles within the pit, and to subsequently cover the desiccated tailings with spoil. In covering the desiccated tailings, sufficient fill must be placed to enable safe access for construction plant. However, the addition of too much fill can cause "bow wave" failures if the bearing capacity of the crust is exceeded. If mixing of the tailings and spoil is desired, spoil must be placed before crusting of the tailings surface. Technical difficulties associated with storing tailings slurry within spoil pile valleys include the seepage of tailings water into the spoil and its impact on the overall water balance, on spoil pile stability, on inflows into the pit, and on the ground water.

5. CO-DISPOSAL

A promising new coal mine washery waste disposal technique has emerged which involves the co-disposal of coarse reject and tailings slurry by combined pumping. This technique is employed at Jeebropilly Mine in the Ipswich Coalfields. The mixture has greatly enhanced engineering properties over those of tailings only, and there is potential to form a self-supporting elevated landform on disposal of the mixture. The formation of an elevated landform would obviate the need for a substantial containment structure. A catch drain and small dam would serve to collect the water emanating from the mixture. The inclusion of tailings with the coarse reject may also lead to a reduction of any oxidation of the coarser particles. The combined coarse reject and tailings slurry is far more permeable (by 3 or 4 orders of magnitude) than tailings only, and therefore settles out rapidly to form a mixture of reasonable engineering properties. It achieves an average surface slope or about 1 in 15 (compared with about 1 in 100 for tailings only), which may be suitable as a final landform, obviating the need for expensive rehandling of the waste material.

The delta which forms on co-disposal is immediately trafficable. Particle sorting on the surface of the delta formed at Jeebropilly Mine exhibits a significant trend of increasing particle size with increasing distance down the delta from the discharge point (Figure 3, obtained by dry sieving since considerable fines attach themselves to the coarse particles depositing on the delta). Also shown in Figure 3 is the input particle size distribution (pipe sample). The particle size distribution on the delta is everywhere finer than that input due to breakdown of the material on exposure. The explanation for the apparent anomaly of increasing particle size down the delta is the variation in the specific gravity of the particles deposited down the delta (Figure 4). Close to the discharge point (10 m), there is little variation of specific gravity with varying particle size, and the specific gravity is relatively high, at about 2.2. Towards the pond (90 m), the specific gravity of the deposited particles is much reduced and decreases significantly with increasing particle size.

The particle size distributions of samples recovered from 500 mm beneath the surface of the delta are reasonably uniform with distance down the delta from the discharge point (Figure 5, obtained by dry sieving). This is attributed to the infilling of the voids between the coarse particles deposited towards the pond with segregated fines. Other fines are carried as wash load to the pond.

At Jeebropilly Mine, the solids concentration at which the combined wastes are pumped averages 30% by weight. While a high proportion of the fines attach themselves to the coarse particles deposited on the delta, a substantial proportion of the tailings together with fines produced by material breakdown on the delta, find their way to the pond, where they sediment out. The segregation of fines could be substantially reduced by pumping the mixture at a higher solids concentration and at lower velocity. Segregation would also be reduced by increasing the length of flow over the delta. Meandering bunds could be constructed to achieve this by pushing up deposited material on the delta. The location of the pipe discharge point could also be varied to considerable advantage.

There is a need to establish what proportion of tailings can be

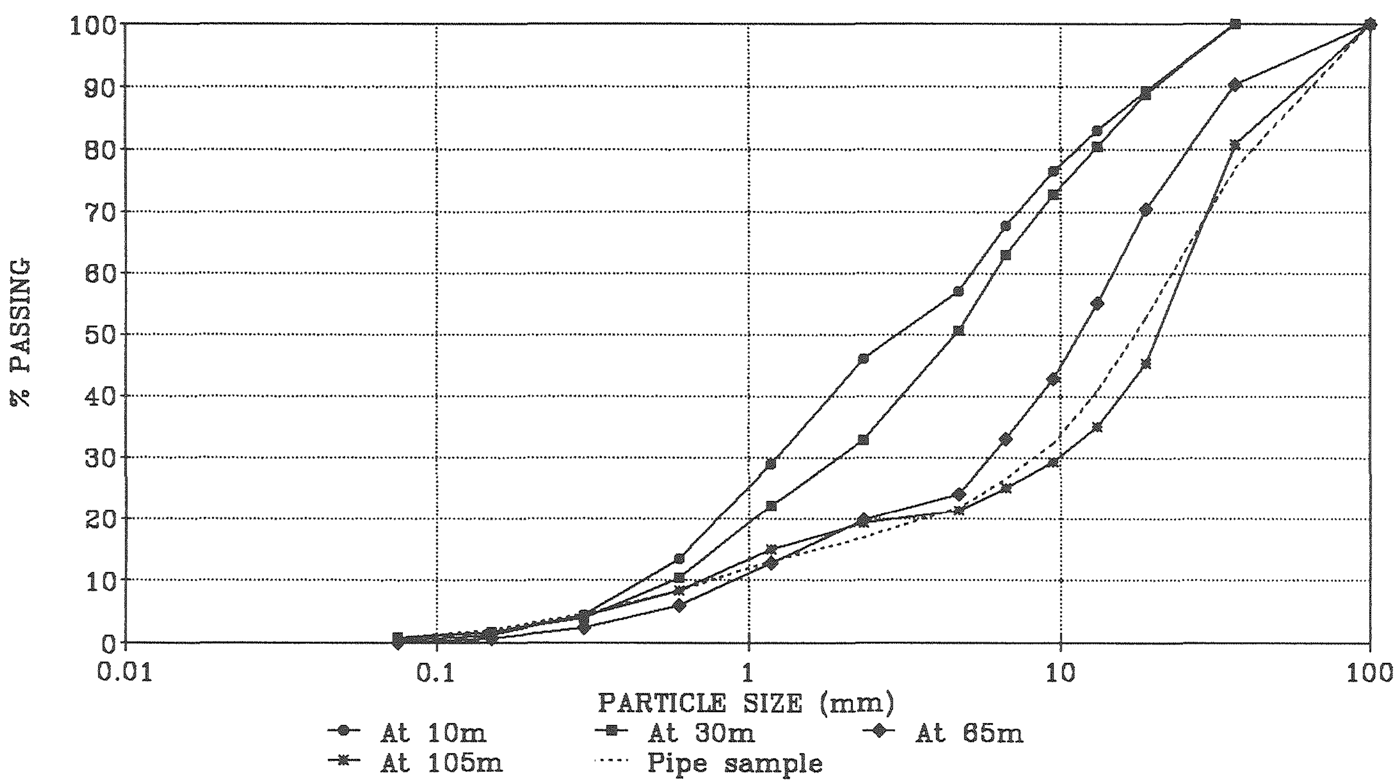

Figure 3:Hydraulic sorting of particles with distance from discharge point on surface of co-disposal delta at Jeebropilly Mine, Ipswich Coalfields.

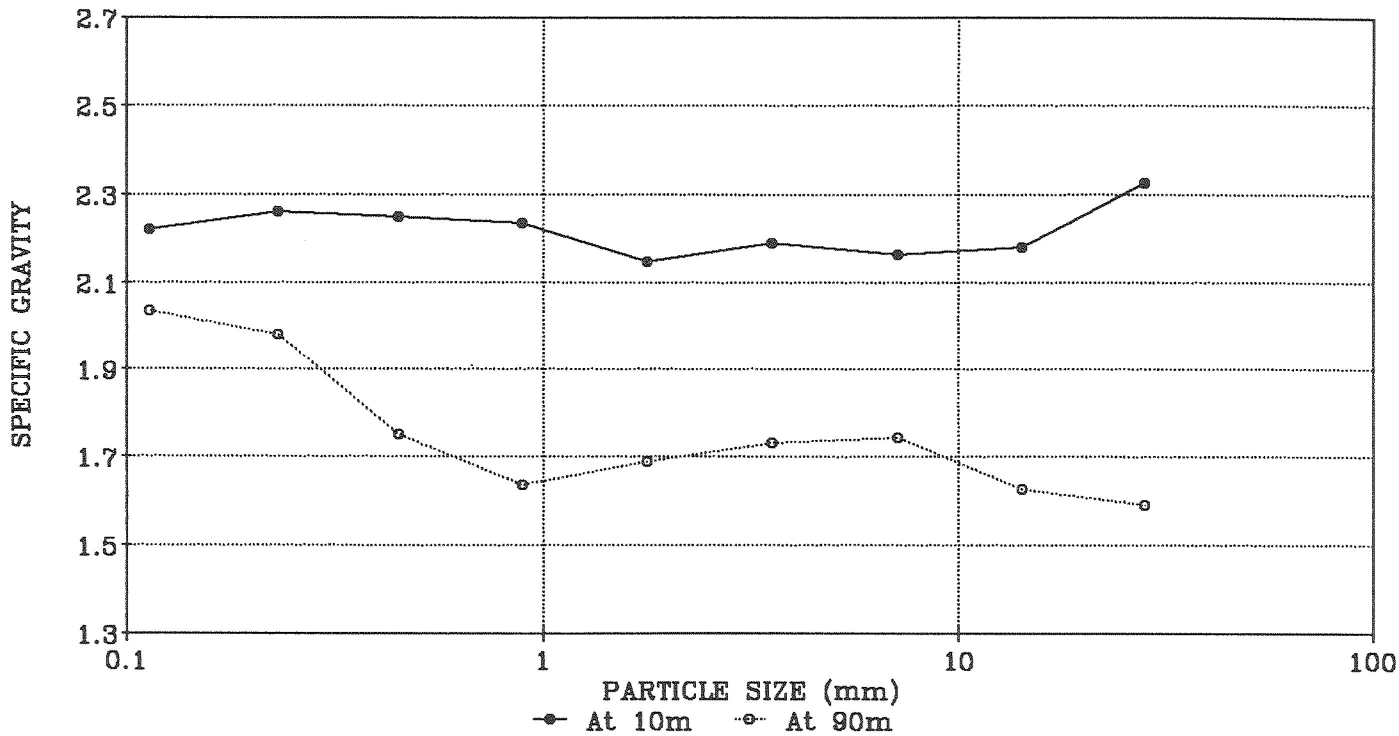

Figure 4:Variation of specific gravity with particle size and distance from discharge point for surface samples from co-disposal delta at Jeebropilly Mine.

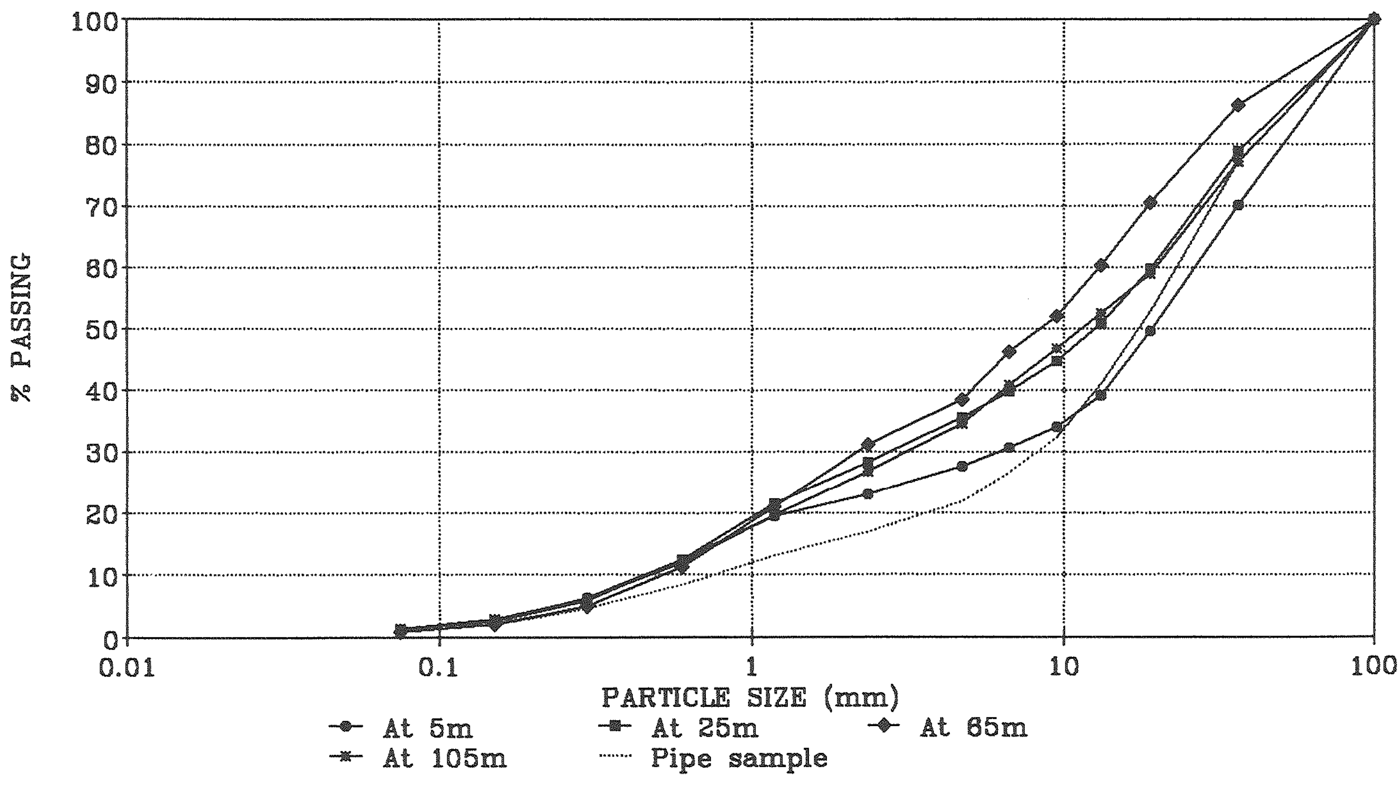

Figure 5: Hydraulic sorting of particles with distance from discharge point 500mm beneath surface of c0-disposal delta at Jeebropilly Mine

accommodated within the pore space between the coarse reject, since a high proportion of tailings is a feature of some mines. An acceptable shape for the final landform must be defined, and the choice of an appropriate surface treatment made. The technique of co-disposal remains to be proven for other washery waste materials at other mine sites. As conditions vary between coal mines, and even at the one coal mine over time, the need for other alternatives should not be discounted at this stage.

6. CONCLUSIONS

Coal mine washery waste disposal and storage options must be developed which meet enhanced environmental standards aimed at ensuring sustainable mining development, while minimising the initial, ongoing maintenance, and future rehabilitation costs involved. The co-disposal option, involving the combined pumping of coarse reject and tailings slurry, ideally to an elevated landform, offers the best potential technically, economically, and environmentally. It remains to carry out the research necessary to optimise this technique and ensure its successful application at a range of coal mines having different washery waste materials and conditions. Application of the technique to mining operations other than coal may also be possible.

In order that the mining industry not forfeit the potential to exploit mineral resources, it must demonstrate that sustainable mining development is possible, compatible with community environmental expectations and the very real need to protect the environment. The key issue is the need for the engineered disposal of mining wastes to ensure that the environment is protected. Mining in the past has focused on the short term imperative of a "contain and forget" approach to that non-productive side of mining activity involving the handling of the wastes produced. Successful engineered mine waste disposal and rehabilitation removes a potential future liability, which is threatening the viability of many existing mines.

7. ACKNOWLEDGMENTS

The research on which this paper is based was carried out under National Energy Research, Development and Demonstration Council Project #1264, which was completed in March 1992. The co-operation of the managements of Aberdare Colliery and New Hope Corporation Ltd, owner of Jeebropilly Mine, in allowing access to their mines for sampling and testing of washery waste materials is appreciated. The assistance of Dr Peter Morris, V. Kuganathan and Peter McMillan of The University of Queensland, in the collection of data included in this paper, is gratefully appreciated.

LANDSLIDE STABILISATION AT THE CLYDE POWER PROJECT: A MAJOR GEOTECHNICAL UNDERTAKING

M D GILLON, ME, MIPENZ[1]

Construction work on one of the world's largest landslide stabilisation projects is drawing to a close in Central Otago. Begun in mid 1990, major stabilisation work has been carried out on seven large rockslides which will be partly inundated when the Clyde dam reservoir (Lake Dunstan) is filled. The work has required the construction of 14.5 km of tunnel, 60 km of surface drilling, 78 km of drilled drainage holes and 5 million cubic metres of earthworks. The stabilisation programme has been carried out by the Electricity Corporation of NZ as part of the Clyde Power Project, a hydro-electric development on the Clutha river.

BACKGROUND

The landslide stabilisation work described has delayed electricity generation from the Clyde power station. Review of the reservoir slope stability in 1987, utilising information from the major reconstruction of SH8 in the Cromwell gorge, led to the identification of complex groundwater conditions. These conditions were quite unlike those previously encountered in the Cromwell Gorge and were considered unfavourable for the stability of the reservoir slopes. Intensive investigations followed and identified other similar areas. Lake filling, planned for September 1989, was delayed while investigations and a reassessment of slope stability continued.

The Cromwell Gorge landslides are subtle features, lacking prominent scarps or markedly hummocky topography. They developed at least 50 - 150,000 years ago and are either dormant or creeping translational rock and chaotic debris slides. The landslides show no evidence of large scale rapid movement. They range in size from 3 million to over 1 billion cubic metres.

At the time of dam site selection in the early 1970's the presence of the Cromwell Gorge landslides was recognised. Stabilisation works were recommended for the Cromwell and Clyde slides because of their location adjacent to the Cromwell township and the Clyde dam respectively. Based on the

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Works Consultancy Services Ltd, WELLINGTON

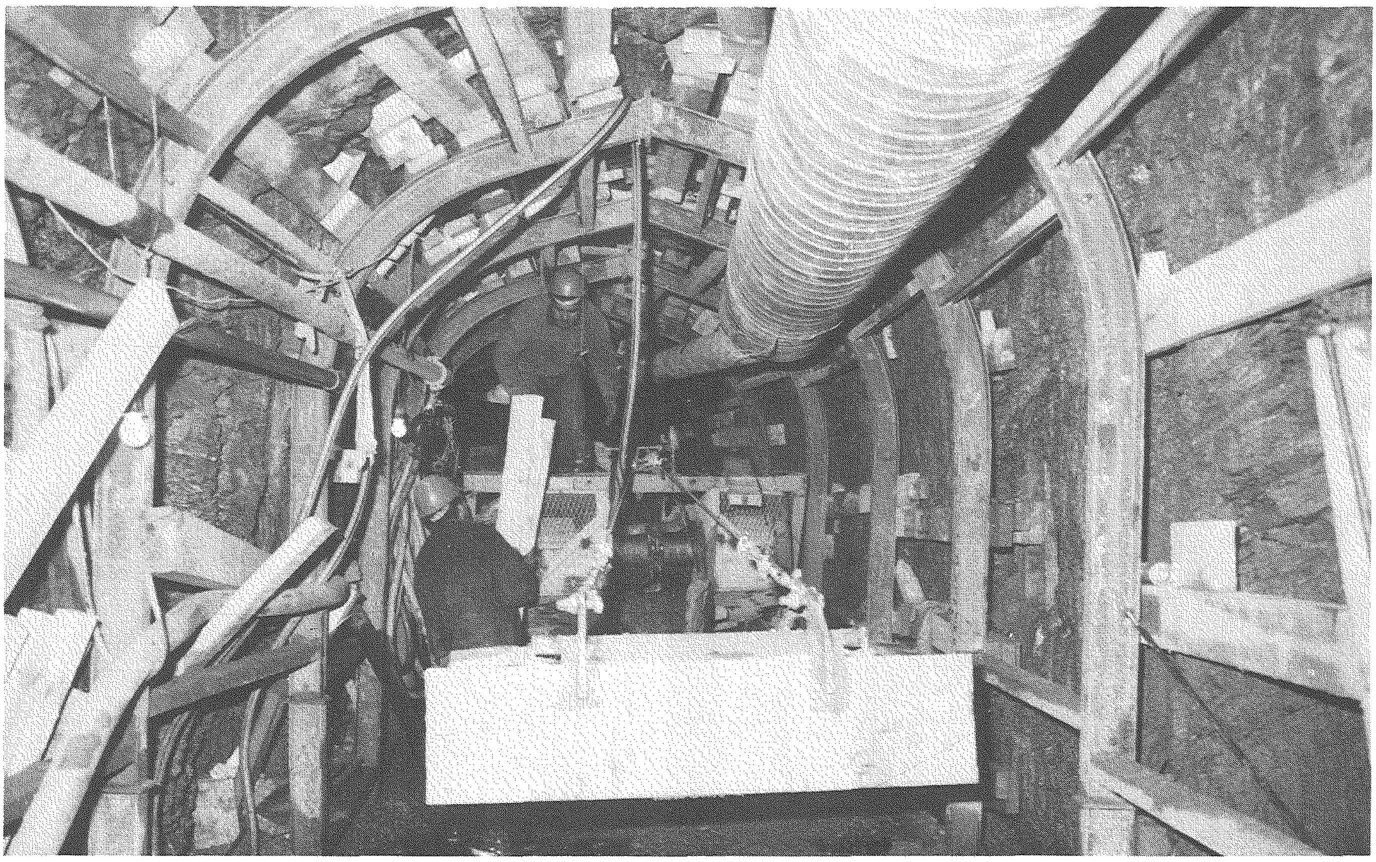

Figure 1. Drainage drive construction at Jackson Creek Slide

general appreciation of other similar landslides within the region at that time, it was not considered that the other landslides required treatment.

These elements of uncertainty were recognised and accommodated in the reassessment of the reservoir slopes by:

STABILITY, HAZARD AND RISK ASSESSMENT

The assessment of rock slide stability, hazard and risk is a challenging assignment for the geotechnical practitioner. The complexity of landslides is often such that observational data can be interpreted in a number of ways. Judgements are necessary at many stages in the assessment of stability, hazard and risk.

- aiming for good quality observational data, recognising that this was the basis on which later judgements would be made
- ensuring observations were separated from interpretation
- integrating the detailed observations to develop summary descriptions of the landslides and their groundwater systems so that sound general conclusions could be drawn
- providing appropriate organisational structures and utilising suitably qualified and experienced staff
- appreciating that the primary role of numerical analysis is in understanding the main factors influencing stability and in determining the relative changes in stability
- accepting that there are no reliable established methods of predicting landslide movements (velocity, acceleration and displacement) in relation to changes in stability
- evaluating the effect of judgements at key decision steps
- providing technical review by both independent specialist consultants and an independent Review Panel with interntional experience in similar work
- providing, where necessary, robust engineering solutions which could accommodate uncertainty.

Stability assessments prepared in mid 1990 described the nature and extent of each landslide, together with the effect of reservoir inundation on their stability so that the level of hazard and risk could be determined. It was found that the level of hazard and risk associated with the larger slides was such that stabilising measures were required to reduce risk to an acceptable level.

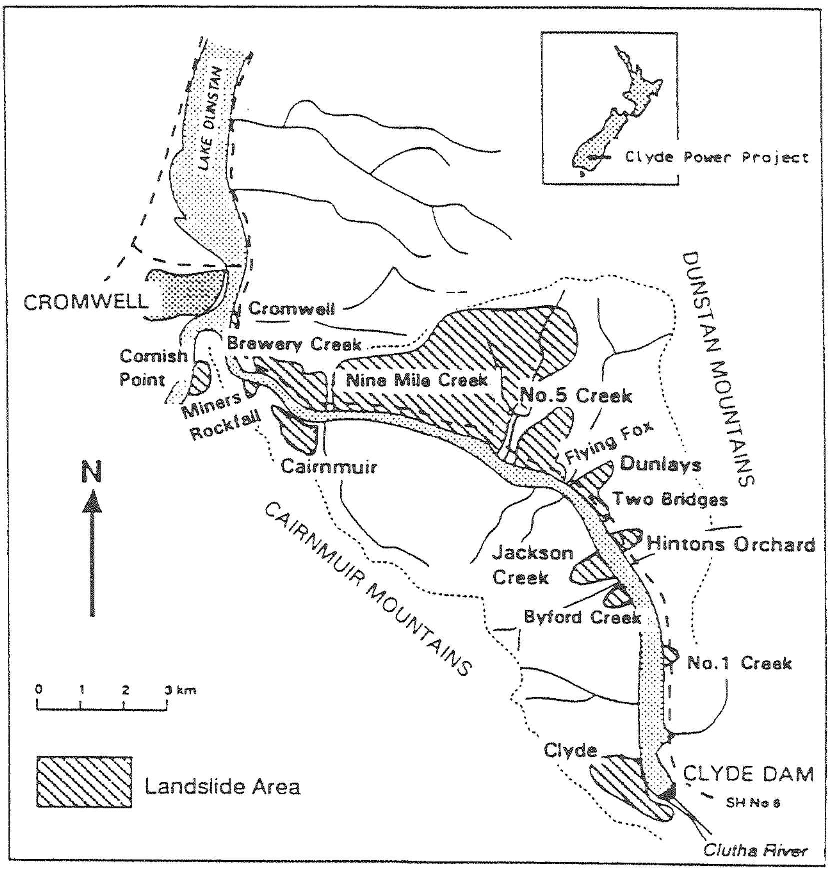

Figure 2. Project location

ENGINEERING WORKS

Drainage measures are widely recognised as the single most effective and economical stabilisation measure for large rock slides. The stabilisation programme developed in mid 1990 was based on tunnel layouts having dual objectives of providing definitive information on the landslides and stabilisation by drainage. The tunnels provided high quality geological observations on the nature of the landslides. Groundwater drawdown due to tunnel excavation also provided valuable information for the planning of underground drainhole patterns.

The concurrent investigation - design - construction activities inherent in this approach required information gained from tunnelling, drainhole drilling and groundwater monitoring to be quickly assimilated and alterations to engineering works promptly actioned. Extensive use was made of computer databases to manage technical information.

In addition to gravity drainage measures, the stabilisation works have also included the construction of toe buttresses in several situations. In the case of the Brewery Creek slide, the combination of a comparatively dry slide mass and a narrow river channel precluded a gravity drainage/toe buttress solution. A low level pumped drainage system was adopted combined with a grouted cutoff and zoned earthfill blanket to limit seepage.

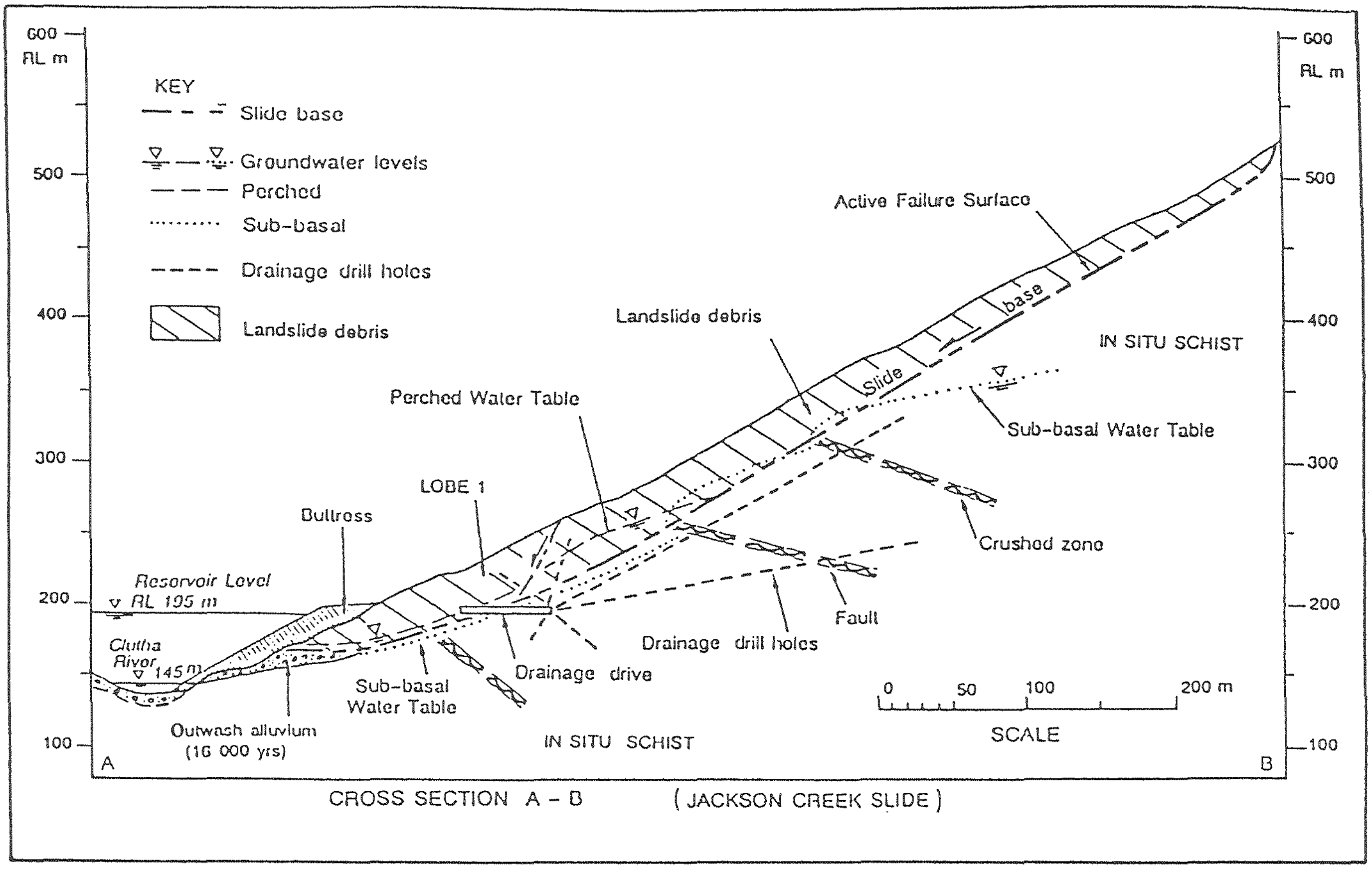

Figure 3. Stabilisation by gravity drainage and butressing works at Jackson Creek Slide

Stabilisation works carried out to date have halted movement at the Jackson Creek, Number Five Creek and Nine Mile Creek landslides.

Contracts for the various engineering works were initially cost reimbursable plus fixed fee so that alterations to the works could be made quickly for maximum overall time and cost benefits. In later stages, when the work was more clearly defined, target cost contracts were negotiated.

INSTRUMENTATION AND MONITORING

Central to the investigation, stabilisation and future management of the landslides are the network of instruments which have been developed for monitoring landslide deformations, groundwater pressures and drainage flows. There are approximately 3500 points being monitored on the Clyde dam and the reservoir landslides during lake filling.

The network includes instruments installed in boreholes, on the ground surface and in tunnels. A range of methods is used for collecting data, including manual recording, logging by electronic datalogger and transmission by telemetry.

Instrument readings are recorded in a computer database which has facilities for raising an alarm if the actual results are outside forecast ranges. The computer system also monitors the actual reading of instruments against the reading frequencies which have been requested so that the planned coverage of readings can be tracked and maintained.

LAKE FILLING

Lake filling will be a closely monitored and managed activity. It will be controlled by the response of the Clyde dam and landslides to inundation and the associated monitoring and evaluation activities. It is expected to start in April-May 1992.

The lake will be filled in a number of stages extending over a 1-2 year period. A high degree of control is available at each stage from the low level sluices and spillway in the dam. Electricity generation will be available from the first stage onwards.

During lake filling the behaviour of the dam and reservoir shoreline will be monitored by both instruments and regular visual inspection. Results will be assessed by experienced staff and reported regularly. Information obtained during lake filling will be used to confirm the geological and geohydrological models of the landslides. These will form the basis of the future management strategy for each landslide.

Following lake filling, monitoring and evaluation of landslide behaviour and the performance of the engineering works will continue throughout the life of the reservoir.

PROJECT ORGANISATION

The stabilisation works described result from the effects of a large, well integrated team working together to meet demanding project deadlines and objectives. The team was assembled by the Electricity Corporation of NZ and included members of their own organisations, staff from Works Consultancy Services Ltd, DSIR Geology and Geophysics, and specialist subconsultants.

The work has been subject to regular review by both specialist subconsultants and an International Review Panel. In their seventh report dated February 1992 the International Review Panel stated *". . . that the geological and engineering work has been well done and equals or exceeds current international practice"*.

The project team look forward to the final stage of the Clyde Power Project - lake filling and generation.

As a postscript to the above, the following update was provided by Murray Gillon in June on progress at that time on the filling of the Clyde dam reservoir:

The reservoir has been filled to El 177 m, 17 metres below normal operating level and 39 metres above the former river level. Filling started on 22 April and was completed to El 177m on 14 May.

All the lower level slides in the Cromwell gorge have been inundated to varying degrees. No shear movements have been detected in the major landslides. There has been minor surface cracking in some of the major road fills and landslide buttresses due to differential settlement following toe inundation.

The instrument network has been further developed and currently there are 5200 instrumented locations. The computer database and data management facilities have performed extremely well and have enabled the design team to confidentially and quickly evaluate the monitoring results.

It is anticipated that performance evaluation of the dam and landslides will be completed to allow the lake level to be raised to El 185 m in August.

Murray Gillon 17 June 1992

MEASURING K_o IN THE TRIAXIAL TEST

Martin Fahey§

1 INTRODUCTION

The sophistication of modern testing methods enables many types of laboratory and field tests to be carried out. However, it is sometimes the case that some types of tests are specified without questioning whether they have any meaning in a particular situation. Because of this somewhat uncritical attitude, some myths have grown up about just what it is that we can and do measure in various tests.

One such myth is that the *in situ* value of K_o, the coefficient of earth pressure "at rest", can be measured by reconsolidating an undisturbed sample of the soil under zero lateral strain conditions, and measuring the horizontal stress required to maintain zero lateral strain. A natural consequence of this myth is that it is often assumed that *in situ* strength and stiffness properties of soil can be best examined in triaxial testing if a sample of the soil is reconsolidated to the *in situ* vertical effective stress while maintaining zero lateral strain conditions. This myth is demonstrably incorrect for practically all realistic situations.

2 K_o IN AN ELASTIC SOLID

Consider the case of a sample of elastic material under some anisotropic stresses σ_v and σ_h (assuming axisymmetric conditions). This stress state results from external forces, and therefore in general the ratio of σ_v to σ_h can have any value. Define this ratio as K_o.

If the applied stresses are removed, the question is whether there is there any way of determining what the initial stress state was. In the "sampling" operation, with the removal of all stresses, the sample will undergo elastic deformations given by:

$$\begin{Bmatrix} \varepsilon_v \\ \varepsilon_h \\ \varepsilon_h \end{Bmatrix} = \frac{1}{E}\begin{bmatrix} 1 & -v & -v \\ -v & 1 & -v \\ -v & -v & 1 \end{bmatrix}\begin{Bmatrix} \Delta\sigma_v \\ \Delta\sigma_h \\ \Delta\sigma_h \end{Bmatrix} \quad \text{.......... (1)}$$

so that:

$$\varepsilon_v = \frac{\Delta\sigma_v}{E}\left(1 - 2K_o v\right) \quad \text{.......... (2)}$$

and:

$$\varepsilon_h = \frac{\Delta\sigma_v}{E}\left[K_o - v\left(1 + K_o\right)\right] \quad \text{.......... (3)}$$

If the sample is recompressed in such a way that the lateral strain during compression is maintained at zero (as in an oedometer test), then the same elastic equations above can be used to show that the ratio of radial to axial stresses is:

$$\frac{\Delta\sigma_r}{\Delta\sigma_a} = \left(\frac{v}{1 - v}\right) \quad \text{.......... (4)}$$

Thus, irrespective of the initial stress condition in the ground (and hence of initial K_o) the K_o measured in the confined compression test is:

$$K_o = \left(\frac{v}{1 - v}\right) \quad \text{.......... (5)}$$

and there is no way in this case that such a test procedure can identify the previous stress state.

3 MEASUREMENT OF K_o IN SOIL

3.1 In situ stress state

The state of stress of soil *in situ* depends primarily on whether it is normally consolidated or overconsolidated. For normally consolidated soil, while the current value of σ_v' is the maximum value ever experienced by the soil (i.e. $(\sigma_v')_{max}$), there appears to be a good correlation between K_o and effective friction angle ϕ':

$$K_{onc} \approx 1 + \sin\phi' \quad \text{.......... (6)}$$

where the additional subscript "*nc*" refers to normally consolidated conditions. This equation is a simplified version of that suggested originally by Jáky (1944).

However, when the vertical stress is reduced below its maximum value, this relationship no longer holds. This is illustrated in Figure 1, which shows schematically the vertical and horizontal stresses in confined compression for initial loading (OA), unloading (AB) and reloading (BD). In the early stages of unloading, the horizontal stress changes at a slower rate than the vertical stress, so that the value of K_o increases. The limit to this behaviour corresponds to the initiation of passive failure (at C in this case). If reloading occurs at B, the curve eventually rejoins the virgin loading curve.

It can be seen from this Figure that for any given vertical effective stress $(\sigma_v')_i$, the horizontal stress could be anywhere between the values corresponding to points E and F, depending on how many cycles of loading and unloading below the maximum past stress occurred, so that K_o can have a wide range of values.

An investigation of data from 170 soils was undertaken by Mayne and Kulhawy (1982), who found that K_o for the first unloading stage (K_{ou}) depends on overconsolidation ratio (OCR):

$$K_{ou} = K_o \text{OCR}^{\sin\phi'} \quad \text{.......... (7)}$$

§Geomechanics Group, The University of Western Australia.

with K_{onc} being given satisfactorily by Equation 1. They went on to derive a general expression for K_o which applies to initial loading, first unloading and first reloading:

$$K_o = K_{onc}\left[\frac{OCR}{OCR_{max}^{(1-\sin\phi')}} + \frac{3}{4}\left(1 - \frac{OCR}{OCR_{max}}\right)\right] \qquad (8)$$

in which OCR_{max} is the value of OCR at the point where the vertical stress is a minimum in the cycle. This expression gives a picture similar to that shown in Figure 1.

It is clear therefore that whereas in an elastic solid, the relationship between vertical and horizontal stresses at all stages "zero lateral strain" loading, unloading and reloading is constant (Equation 4), this is not the case for soil.

3.2 Sampling and testing

When considering the stress changes which occur during sampling and subsequent recompression, an important distinction must be made between fine grained saturated soils and coarse grained or partially saturated soils. Essentially, the difference in behaviour is due to the ability of the fine grained soils to remain at the same mean effective stress due to suctions in the sample, whereas in the coarser grained soils, which are incapable of maintaining significant suctions, the mean effective stress state must change. Consider each type of soil in turn:

3.2.1 Fine grained saturated soils

For soils with sufficiently low air-entry value, the process of removing a sample from the ground can be assumed to be undrained. Consider a sample in the ground at a depth 10 m below the ground surface, and a water table at the ground surface. Assume $\gamma = 20$ kN/m^3, and $\gamma_w = 10$ kN/m^3, and that K_o is 2.5 (say). Thus, $\sigma_v = 200$ kPa, $\sigma_v' = 100$ kPa, $\sigma_h' = 250$ kPa, and $\sigma_h = 350$ kPa. This give a mean effective stress of 200 kPa, a mean total stress of 300 kPa.

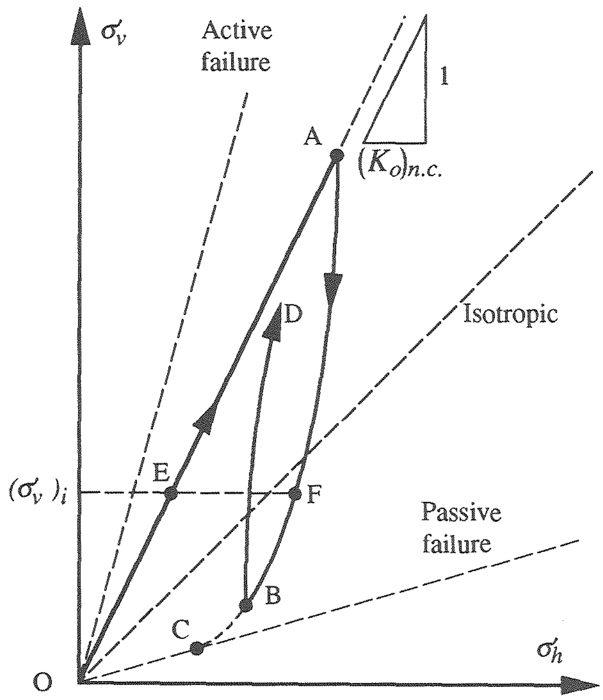

Figure 1. Stress changes during initial loading, unloading and reloading.

Removing this sample from the ground involves reducing the mean total stress to zero, a change of – 300 kPa. If the mean effective stress is to stay the same, the pore pressure must change by the same amount as the total stress. Thus the new value of pore pressure is 100 – 300 kPa, or – 200 kPa. At this stage, though the mean effective stress is unchanged, the vertical and horizontal stresses must be equal (and hence are equal to 200 kPa). Thus, the sample has undergone an increase of 100 kPa in σ_v' and a reduction of 50 kPa in σ_h'. The sample will then have changed shape, even though the volume will theoretically be the same. In reality, some expansion of the sample is inevitable, due to the fact that the pore water goes from compression to suction, with consequent appearance of some air bubbles.

In the re-consolidation stage, assume that we know what the *in situ* values of σ_v' and pore pressure were. There are then a number of possible approaches to discovering what the horizontal effective stress is:

♦ Measure the suctions in the sample when in the unconfined state. The difference between the suction and the *in situ* pore pressure should be equal to the change in mean total stress in the sampling operation, which is equal to the *in situ* mean total stress. From this, and a knowledge of the *in situ* vertical effective stress, the *in situ* horizontal stress can be calculated.

♦ Apply total stresses to the sample in a completely undrained mode, and measure the pore pressures. The correct stress state will have been reached when the total vertical stress is equal to the *in situ* total vertical stress and the horizontal stress has been adjusted such that the pore pressure is equal to the *in situ* pore pressure. This would be valid only if it was certain that the *in situ* pore pressure was hydrostatic, or if it had been measured in some way.

Just as in the sampling operation, the undrained recompression should in theory result in zero volumetric strain, but again the water may be compressible in going from suction to compression. Thus, the second option should produce a better estimate of the *in situ* stress state, as it relies on re-establishing the *in situ* pore pressure rather than relying on equality between total stress and pore pressure change in the sampling operation.

3.2.2 Free-draining soils

In a free draining soil, some suctions may develop in the sample during the sampling operation, but these suctions will not be sufficient to maintain the sample in the same mean effective stress state. If the sample is overconsolidated, *there is no direct way of finding out what was the value of the in situ horizontal stress from the sample.*

This is especially the case where, as is common in triaxial testing, the sample is allowed to saturate for some time before commencing the re-compression phase of the test. This process will wipe out all suctions in the sample, and hence remove any evidence of past stress state. At the end of the re-saturation, the sample will be under zero effective stress, and will have undergone some vertical and horizontal strain during the whole sampling and re-saturation process. Thus, a subsequent "zero lateral strain" re-compression will do no more than provide a measure of Poisson's ratio (ν), as for an elastic solid (Equation 4). The correct horizontal stress to apply would be that which reverses the horizontal strain occurring during sampling and re-saturation. Only if that is zero will the zero lateral strain test provide the correct value of *in situ* horizontal stress.

However, it must be concluded for overconsolidated free-draining soils that there is no hope of determining the horizontal stress from a "zero lateral strain" test. In fact, this type of test can provide only a measure of Poisson's ratio, since the K_o measured in this test is a unique function of Poisson's ratio (Equation 5), and irrespective of the true degree of overconsolidation and the true *in situ* value of K_o, must always give a K_o value less than 1. Hence, as an indicator of the *in situ* value of K_o in overconsolidated soils, the test is worthless.

4 CONCLUSION

Measurement of horizontal effective stress remains one of the most difficult problems in geotechnical engineering. Under ideal circumstances (with fine-grained soils of very low permeability), it might be possible to get some idea of the *in situ* stress state by measuring the suctions in the sample, or by carrying out undrained re-compression with pore pressure measurement.

5 REFERENCES

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Mayne, P.W. and Kulhawy, F.H. (1982). K_o – OCR relationships in soil. *Journal of the Geotechnical Engineering Division*, ASCE, Vol. 108, No. GT6, 851–872.

STANDARDS AUSTRALIA

The last two issues of Australian Geomechanics gave an update on the status of Standards and associated committees that were of relevence to members of the Society. They were:

AS3798—Guidelines on Earthworks for Commercial and Residential Development

AS1289—Testing of Soils for Engineering Purposes

AS1726—Site Investigation Code

AS2159—Australian Piling Code

AS2870—Residential Slabs and Footings

AS3706—Geotextiles—Methods of Testing

Committee CE/26 Precast Reinforced Concrete Box Culverts

Since then however there has been little to report. One new development is that AGS has been invited by Standards Australia to nominate a representative to the new committee responsible for developing a draft standard entitled:

CE 32—Reinforced Soils and Retaining Structures

[Ed comment: its reassuring to see Standards Australia are keeping up with new developments.]

In addition two draft standards were recently issued for public commment:

(i) DR 92090:R Methods of testing soils for engineering purposes: Method 2.1.6. Soil moisture content tests—determination of the moisture content of a soil—Hotplate drying method (subsidiary method). Closing date for comment was 31.07.92.

(ii) DR 92097: Piling—Design and Installation. This is the draft of the new Australian Standard Piling Code which will replace AS 2159—1978. The draft code has been formulated in limit state format, and comprises mandatory sections, and informative appendices which provide commentary to parts of the mandatory sections.

The draft code was originally issued for public comment until 30 September, 1992 but in view of the interest and debate generated, the deadline for comments was extended to the end of October 1992. Copies of the document can be obtained for $30.00 from:

Standards Australia Att . P. Walsh
Standards House 80 Arthur Street North Sydney NSW

Members with an involvement or interest in deep foundations are urged to obtain a copy and actively participate in the review process.

Since there is little to report from the SA committees in this issue, its worth reminding readers that this regular feature is also intended to provide a forum for members to comment on their experiences good or bad, in using the various geotechnical standards. Such 'open discussion' could provide important feedback to the Standards' Committees with the possibility of improvement in these all important reference documents.

NEXT ISSUE

Before telling you about the next issue, we would like to take this opportunity to say goodbye.
This is the last issue of Australian Geomechanics (for many years at least!) that will be produced by a Western Australian Editorial Panel. Whilst the task has sometimes seemed onerous, there is no doubt that it was all worthwhile. The pleasure of seeing the work completed might be compared with the joys of childbirth. There certainly was quite a lot of pushing, not a small amount of groaning but we can tell the Victorian Editors that breathing exercises are of no help whatsoever (although they do help to pass the time!)

We have all enjoyed the effort that was required and although we only managed to elicit one Letter to the Editor (despite attempts at being controversial), we do know that there are some people out there who read the magazine because, at long last, we have managed to extract a State Group report from SA (Loud cheering from offstage!)

For the next two years, Australian Geomechanics will be produced by an Editorial Panel nominated (conned?) by the Victorian Group and based at Monash University. The Panel will be led by Dr Chris Haberfield and we wish him and his co workers all the very best.

And now....the moment you have all been waiting for..... the next issue will centre around.....Research in Australian Geomechanics!

Over to you Chris!

GEONEWS

GEOTECHNICAL "GOINGS ON" IN THE WA GOLDFIELDS

In 1990 several mining and geotechnical engineers based in the Kalgoorlie area formed a group called the Goldfields Geotechnical Group (GGG). The purpose of the group was to promote geotechnical science and to provide a forum for the exchange of ideas in the field of Rock and Soil Mechanics. The group was lead by D Fotakis and P Loubser and, in 1991, organised seven meetings during which internal and external presenters lectured on new solutions and achievements in mining rock mechanics.

During the GGG meeting on 6 March 1992, members indicated their willingness to join the AGS as a local group. As a result, on 7 April 1992, a meeting of the group unanimously voted to transform the Goldfields Geotechnical Group into the Kalgoorlie Group of the Australian Geotechnical Society.

The group consists of eleven AGS members and twelve supporting members who are expected to join in the near future. Anyone interested in the activities of the group are invited to contact Trevor Little at the West Australian School of Mines Tel: (090) 805155.

Details of the 1992 Programme of the Kalgoorlie Group are given in the State Group Reports.

CENTRE FOR GEOMECHANICS IN WESTERN AUSTRALIA

A Centre for Geomechanics has been established in Western Australia in June 1992 for the purpose of servicing the technological and scientific needs of the state's mining and petroleum industries. As a co-operative venture, the Centre is able to draw upon the combined talents of its five primary participants, namely the UWA Geomechanics Group, CSIRO Division of Geomechanics, the WA School of Mines, the UWA Dept of Geology and the WA Dept of Mines.

The aim of the Centre is to promote a vigorous, world class, centre of research excellence and postgraduate education in geomechanics, with particular emphasis on its application to the mineral and energy extraction sections of Australia's resource industries. Expertise will be available across the full breadth of geomechanics from soil and rock mechanics, numerical and experimental modelling, structural and engineering geology, mining geomechanics and rock and groundwater chemistry. Close links with industry will be maintained through Dept of Mines and also through the Board of Management of the Centre, which has strong industry representation.

Companies who are affiliate members of the Centre will have priority access to research personnel, training facilities/courses as well as the Centre's reports, reference and data gathering systems.

Further information about the Centre may be obtained by contacting RJ Jewell, the Centre's Director, on tel. (09) 380 3300 or fax (09) 380 1130.

HOT OFF THE PRESS

'Embankment Dam Engineering' by Robin Fell, David Stapledon and Patrick Macgregor (AA Balkema Publishers) has recently hit the stalls and will hopefully be reviewed in a future issue of the Journal. The aim of the book according to pre-release publicity from publishers AA Balkema, is 'to present a "state-of-practice" on embankment dam engineering, particularly highlighting common problems, errors and omissions' - sounds interesting!

HONG KONG GCO PUBLICATIONS

Geotechnical Control Office, Hong Kong publish a series of relatively inexpensive and comprehensive geotechnical guides, manuals and reports which include titles such as :

Geotechnical Manual for Slopes
Guide to Retaining Wall Design
Guide to Site Investigation
Guide to Rock and Soil Descriptions
Model Specification for Prestressed Ground Anchors
Model Specification for Reinforced Fill Structures
Groundwater Lowering by Horizontal Drains
Review of Design Methods for Excavations

Further information on the publications available may be obtained by writing to:

Publications (Sales) Office
Information Services Department,
Battery Path,
Central,
Hong Kong.

CONFERENCE WATCH

In February of this year, the New Zealand Geomechanics Society and Christchurch, New Zealand were host to a unique 'double' on the conference circuit, namely the 6th Australian New Zealand Conference on Geomechanics and the 6th International Symposium on Landslides.

6th ANZ Geomechanics Conference

The Australian New Zealand Conference On Geomechanics ran from February 3 to 7, was attended by over 150 delegates and had as its overall theme "Geotechnical Risk - Identification, Evaluation and Solutions". Major Sponsor for the conference was the New Zealand Earthquake and War Damage Commission (EQC).

An excellent introduction to the conference was given by Professor J. K. Mitchell, University of California, Berkeley in his keynote address entitled "Mitigation of Ground Failure Risk - Some Lessons from the Loma Prieta Earthquake".

Aftermath of the 1989 Loma Prieta earthquake in California, displayed graphically in a series of colour slides, was used by Professor Mitchell to illustrate how geotechnical risk has been identified and evaluated in the Marina District of San Francisco. This was then used as a basis for recommendations for actions to prevent loss of life and massive damage in future large earthquakes. The latter included site specific programmes of ground improvement to prevent liquefaction and lateral spreading in critical areas, seismic retrofitting of deficient structures, upgrading of utility systems and the development of emergency response plans.

The conference was also the venue for the John Jaeger Memorial Address which was given by Dr B.G. Richards, CSIRO, on the subject "Modelling Interactive Load-Deformation and Flow Processes in Soils, including Unsaturated and Swelling Soils." The concept model was developed over 25 years as a finite element computer program incorporating the theoretical and practical experience gained by the author in his widely acclaimed research work over the period. Of particular interest were the practical applications of the model which included back analysis of the Sau Mau Ping landslide in Hong Kong ,1972, in which 18 people were killed; prediction of pressures due to swelling soil on a retaining wall and hill-slope seepage in a soil with contrasting texture.

Over 90 papers were included in Conference proceedings and were discussed by Session Reporters under the following categories:

Session 1: Earth Structure,Dams, Soil Improvement and Geofabrics. 13 papers

Session 2: Foundations and Retaining Walls. 16 papers

Session 3: Mining, Tunnels and Excavations 13 papers

Session 4: Soil Properties and Testing. 23 papers

Session 5: Analyical and Probabilistic Methods 13 papers

Session 6: Slope Stability and Seismic Hazard. 13 papers

Session 7: Professional and Legal Issues. 4 papers including one by Peter James which really required a category of its own.

Of particular note was the Session Report from Prof John Carter who managed to present a very clear, informative and well balanced analysis of the 13 papers on Analytical and Probabilistic Methods - subject matter that potentially could be 'heavy going' for the uninitiated.

As might be expected the 90+ papers reflected a broad interpretation of the Conference theme of geotechnical risk. Having a specific theme however did focus conference discussion and as a result some key issues were identified and debated. Those requiring urgent consideration by the profession included:

a) the need for common understanding and consistent terminology for terms such as risk, hazard and uncertainty and

b) the need for education within and outside the profession in the concept of uncertainty and risk associated with engineering works.

Final day of the conference saw a polished presentation on the Clyde Power Project by M Gillon, Works Consultancy Services. This was followed by the NZGS Geomechanics Lecture, given by Professor G.R Martin, University of Southern California, on the subject "Geomechanics—The Art and The Science". By way of illustration in his talk, Professor Martin discussed recent developments in cone penetrometers, spectral analysis of surface waves, centrifuge modelling, instrumented pile load tests, finite element analysis and the future use of computers.

6th International Symposium on Landslides

The Symposium ran from February 10 to 14, 1992 and was attended by over 220 delegates, of whom about 90 were from either Australia or New Zealand. Major financial sponsors were EQC and Electricorp Production and the symposium was co-sponsored by ISRM, ISSMFE and IAEG. It is the first time the symposium has been held in the southern hemisphere and it attracted over 224 papers. The conference assumed a special significance in the context of the present United Nations International Decade for Natural Disaster Reduction Programme.

Technical sessions were introduced by general reports on the session themes from keynote speakers as follows:

General themes:

Landslide Investigations. Prof D H Stapledon (Australia)

Stability Analysis Techniques. Dr N R Morgenstern (Canada)

Stabilisation & Remedial Works. Dr R L Schuster (USA)

Landslide Hazard Assessment. Dr J N Hutchinson (United Kingdom)

Monitoring & Instrumentation. Mr J Dunnicliff (USA)

Specialist themes:

Seismicity & Landslides. Prof K Sassa (Japan)

Landslides & Reservoirs. Dr W Reimer (Germany)

Open-Pit Mine Slopes. Dr B K McMahon (Australia)

Slope Instability in Tropical Areas. Dr E W Brand (Hong Kong)

Landslides in Australasia. Prof R Fell (Australia) & Dr W M Prebble (New Zealand)

With such a wide range of themes and large number of papers it was impractical and probably inappropriate to mention individual contributions, suffice to say that there were some excellent presentations from keynote speakers and the interested reader is referred to the 3 volumes of Proceedings for further information.

Of particular interest to delegates was the massive landslide stabilisation programme nearing completion around the shoreline of the proposed Lake Dunstan, in southern New Zealand. This hydro-electric storage is to be impounded behind the completed Clyde Dam in the schist terrain of Central Otago, where large (<1000Mcu.m)ancient landslide complexes pose a potential threat to the long term operation of the scheme. Some 15 papers dealing with various aspects of landslide stabilisation programme on the Clyde Power Project were included in the conference proceedings. In addition delegates had the opportunity in a pre-symposium study tour to visit the site and to gain an appreciation of the nature and scale of the remedial works. The landslide stabilisation programme is reputedly the largest known in the world and is costing NZ$400M (US$220M).

Keynote address "Landslide Hazards and their Mitigation in the Himalayan region" never materialised as at the eleventh hour, the speaker, Prof V D Choubey (India) was unable to attend.

Reports to the conference from the UNESCO Working Party on World Landslide Inventory included an update from Dr B Brown of US Geological Survey on current status of the inventory and a request for all available details of landslides to be submitted via national representatives (R Fell, Australia), to the USGS Landslide Centre.

Ed Note: I'm sure all conference delegates will wish to join with us in congratulating both the New Zealand Geomechanics Society and Guthreys Pacific Convention Planners on two excellently organised conferences.

PRESS INTERFACE

"TLC threat to ban export of WA waste"
"PM buckets poor waste strategies"
"Tonnes of waste to wait at Fremantle"
"Toxic waste exports to UK banned"
"Toxic waste plan under cloud"
"The political morass of intractable waste"
"More waste, less speed"
"Premier rises to smelly event"
"Do not rubbish the idea of efficiency"
"Once and Future Landfills".

This is just a selection of snappy headlines from various publications around the nation in recent time. Headlines over articles which focused readers on a rubbishy subject. Your esteemed journal - with this issue - has joined the throng pursuing journalistic zeal towards what is a rather consuming topic of the '90's.

In this endeavour we join rather august company, as evidenced by the last listed headline. It comes from none other than the National Geographic. This article published part way through last year, was sub-titled "Garbage Archaeology" and proved to be a fascinating look at the garbage industry in the USA. The introduction, printed alongside a photograph of a compactor, track deep in rubbish and surrounded by a flock of seagulls, set the scene by posing the question *"How will we dispose of our trash when dumps like this one in New York City are full? Discoveries by garbage archaeologists clarify our options."*

The photograph could have been taken at any one of a hundred locations in Australia and the question posed by the leader writer is just as relevant to Australia as it is to the USA.

The article was of course generously interleaved with high quality photography and neat graphics for which "NG" is famous. The article revealed that the "archaeological" work showed US garbage consists of about 50% paper. The picture in Oz is unlikely to be very different so it is obvious that the Nation's journalists must lift their standard so that the bulk of the written word is retained for its value to posterity otherwise we may be over-taken by a sea of waste.

I do hope that Issue No 22 of Australian Geomechanics does nothing to contribute to the problem.

On a different level, the problems of dealing with intractable wastes have also received a lot of press coverage. The biggest problems in this arena are of course political. Back in 1990 or so, the then Environment Minister, Barry Cohen wrote a couple of excellent articles published in The Australian and The Bulletin which provided a real insight into the political problems associated with disposing of the toxic by-products of our current age. Unfortunately the in-sight from these articles doesn't seem to have provided enough light for Mr Cohen's successors to make any real inroads into finding a solution. In this case the politicians can be assured that ignoring this problem will not see it go away.

More recent headlines bear testimony to the fact that the problem and the waste are both still very much with us.

Political progress is however being made in the landfill area with the WA Premier (that affable Lady dubbed *"Dr Feelgood"* by the local press) gaining some kudos by announcing the go-ahead for an ambitious methane gas collection facility. The gas is to be used to generate electricity for a sports centre with excess capacity sold to the SEC. The headline which accompanied the article may have dampened the *feel* of the event for the *good Doctor* as the West Australian lead with ***"Premier rises to smelly event"***

Back to things "Geographic" and a new direction all together. It was a pleasure to see the most recent issue of Dick Smith's "Australian Geographic" and the major article devoted to the Sydney Harbour Tunnel project. Liberally illustrated with great photography and a lift out poster, the article provides a very readable commemoration of a major engineering project.

Predictably, the significant geotechnical aspects of the work didn't rate a mention but it remains an excellent record of a major "geotechnical" project. By the way "The Australian Geographic Society" has once again opened its membership. If you are interested contact *Australian Geographic, PO Box 321, Terry Hills, NSW 2084. Tel:(02) 450 2300 or Fax:(02) 986 3517.*

NATIONAL COMMITTEE MATTERS?

The first National Committee meeting for 1992 was held in Sydney on 10 April 1992. As mentioned in the last issue, it had been planned to hold this meeting in Adelaide but, in the interests of economy, the venue was changed at the last minute. Nevertheless, also in the interests of economy, the meeting was held at the Holiday Inn, Coogee, rather than at the IEAust's facilities in North Sydney.This is not the place to examine why meeting facilities supplied by a commercial operation should be cheaper than those belonging to IEAust, but it does seem to this unenlightened individual that there is something wrong if IEAust cannot provide facilities for meetings at a competitive rate if, indeed, they must charge at all.

Over the past few National Committee meetings, those delegates who can have been getting together for dinner on the night before the meeting. Informal discussions held over a bottle or two of red wine seem to have enabled open discussion and sharing of ideas without the strictures that must be applied during formal meetings.They have also allowed your correspondent to identify those issues of particular interest or importance for the general reader. It is a curious, although perhaps not surprising fact that the interest in any particular topic is much more likely to be a function of the heat it generates during such informal discussions, rather than the space it occupies in the business paper.

The meeting opened at 10am with the (usual) full business paper. One of the first items discussed related to the matter of membership subscriptions and the related issue of IEAust subventions. For all non IEAust members and others who do not know, IEAust offered to pay a $15 subvention (= "grant of money in aid") to the technical society of choice for each IEAust member. Consequently, the subscription for such members was reduced accordingly. This created a nightmare, compounded for the AGS by:

1. significant numbers of non IEAust members;

2. a less than crystal clear IEAust subscription renewal notice, which actually did include an opportunity for payment of additional society subs if appropriate, and

3. the AGS sending all existing AGS members a separate AGS subscription renewal form which did not mention a reduced subscription payment for those nominating AGS as the recipient of the IEAust subvention. Since the AGS renewal forms were sent out BEFORE the IEAust forms, prompt payers had no chance of avoiding the confusion!

Of course all of this confusion was compounded by the usual application of the corollary of the First Law of Engineering "When all else fails, read the instructions". Since all else had not failed (". . . and anyway, I've renewed my subscription dozens of times before"), there was no need to read (decipher?) the accompanying documentation and the result was chaos.

The effects of the resulting mess are still being felt, but we are assured that it will all be sorted out next year. We shall see!

Despite the problems, the National Committee welcomed the action of IEAust supporting Technical Societies like AGS in this manner. It gives recognition and support to our role in the Learned Society function of the IEAust.

It is pleasing to report that the National Committee accepted the proposal to form a Kalgoorlie Group of the AGS. At this time, it has a membership of approximately 20, most of whom work in the mining geotechnics area. Whilst there are a few technical problems to be resolved mostly concerned with setting up a working organisational relationship between the new group, the National Committee and the Perth based AGS Group, the National Committee and the Editorial Panel of "Australian Geomechanics" are very pleased to welcome the new group in Kalgoorlie and we all look forward to a long and fruitful relationship between all parties.

As foreshadowed in the previous issue of "Australian Geomechanics", considerable thought is being applied to the future directions that AGS should take. The National Committee agreed that more consideration needs to be given to this topic, particularly in light of the fact that both the IEAust and the AusIMM seem to be losing sight of their "Learned Society" function, even though it was their perception that most members expected that priority should be given to their professional needs, rather than to the needs of the engineering industry. [1] The matter of the future direction of AGS will continue to be actively considered and discussions with IEAust and AusIMM on this matter are planned.

It was reported in the last issue of "AG" that the Victorian Group were to purchase two videos featuring Prof Ralph Peck. Unfortunately, financial considerations prevented this but we are pleased to announce that National Office has stepped into the breach and bought them instead. Contact AGS National Secretary, Peter May, if you would like to see them.

In light of the success of a similar venture in Europe, it was proposed to hold a Young Geotechnical Professionals' Conference in Australasia. The National Committee accepted the idea and charged its Deputy Chairman, Mr Garry Mostyn to develop a specific draft proposal for the next National Committee meeting in October 1992.

[1] As a sidelight to this issue, the Editorial Panel is disappointed to report that, despite its importance, no correspondence or other communication has been received on this vital matter since the publication of the Editorial in the last issue of "AG". This matter WILL affect each and every AGS member, particularly if the AGS comes out from beneath the IEAust "umbrella" and becomes totally independent. We wonder how many AGS members would resign from IEAust/AusIMM if AGS subscription rates were trebled or quadrupled.

GRAVEL RASH

"THE CLAY FEAT"
BY STEPHEN R JONES

At the annual in-house technical seminar held by D J Douglas & Partners, a geotechnical guessing competition was held. It was dubbed the Clay Feat and we felt that the findings should be shared with the rest of the geotechnical world. An unidentified sample of clay was put on display, and entrants were asked to estimate (guess?) some basic soil properties, namely:

- maximum dry density (Standard)
- optimum moisture content (Standard)
- liquid limit
- plastic limit
- percent passing 75 um
- linear shrinkage

To add some spice, a $2 entry fee was charged. As a further incentive to enter, a $5 fee was charged for not entering. Not suprisingly, everyone entered. Only one person knew the official laboratory results, and although he was not permitted to enter, he did encourage bribery and corruption.. It is indeed a happy reflection on the integrity of our profession that the only act of bribery was perpetrated by the company accountant (A bit of a worry actually).

Scoring was based on a system of penalty points: one penalty point for each percentage point away from the official result. In the case of maximum dry density, entrants received one penalty point for each 0.01 t/m^3 away from the official result. The lowest score would win the handsome prize pool.

The estimation techniques used by entrants ranged from not bothering to look at the sample (relying on geo-psychic instinct), to extended caressing and remoulding of a sample, even dropping a chunk into the Perrier to check dispersive tendency. Most people, however, were satisfied to spend just 20 or 30 seconds peering and prodding the display before putting their reputation on the line.

That evening, during the Seminar Dinner, the ballot box was opened and the estimates entered into a prepared speadsheet. Self-appointed scrutineers ensured no shonky business, while still savouring the pepper steak washed down with Bin 444. Only after all results were 'locked in' were the official values entered; the scores were instantly calculated and sorted. The results were announced over profiteroles and coffee to the merriment of all.

The vital statistics of the sample were as follows:

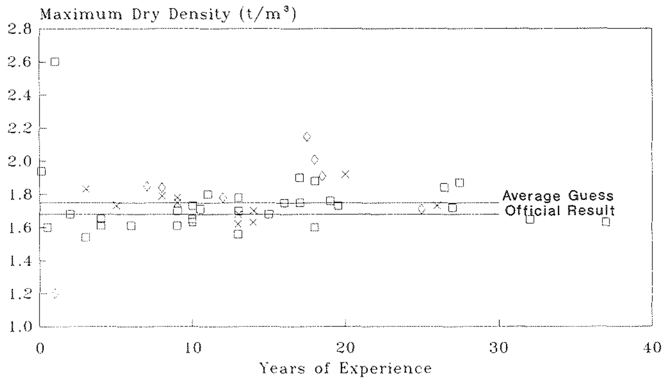
Description:	red-brown slightly silty clay, from Ashtonfield (near Maitland), NSW
Maximum Dry Density:	1.68 t/m^3
Optimum moisture content:	22.5%
Liquid Limit:	62%
Plastic Limit:	17%
Percent Passing 75 um:	92%
Linear Shrinkage:	15%

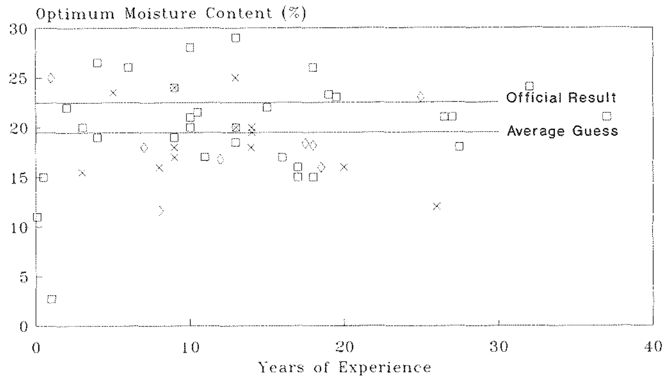
A total of 53 legitimate entries were received. A number of informal entries were received from some non dirt-oriented types who just wanted to save $3. The geochemists, for example, thought that the liquid limit was how much alcohol one could consume before passing out. The company accountant had successfully obtained the correct answers by graft, but not knowing what they meant, incorrectly filled out the entry form, scoring poorly as a result (proving once more that crime does not pay).

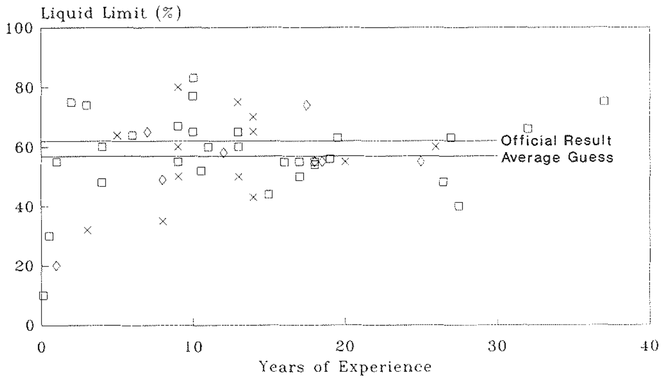
The winning score was 17.5, two experienced engineers tied on first place; their respective guesses were not identical. The highest (worst) legitimate score was 170.5, by a fresh graduate engineer who hadn't yet visited the soil laboratory.

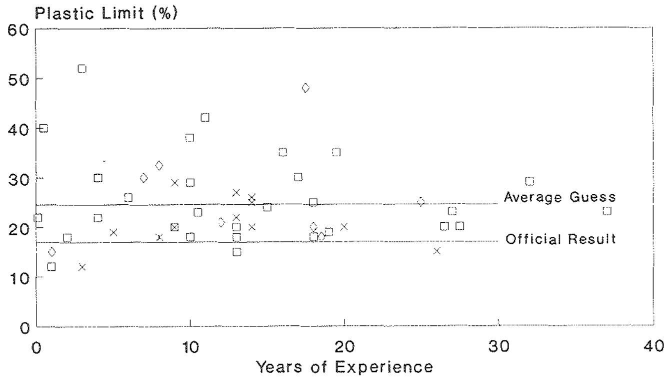
The results are shown plotted on the following graphs. Rather than naming names, the entrants have been placed in 3 broad classifications: Engineers, Geologists and Technicians (only Senior Technical Officers were at the Seminar).

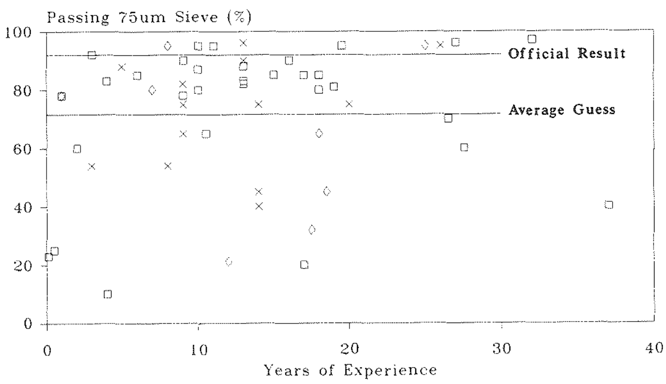
The final plot shows scores against years of experience. Despite the wide scatter, there is a general trend for improved scores with increasing years in the job. It would also appear that years in the job is not the only ingredient for experience, when you consider that 8 of the top 12 scorers are principals (Directors or Associate Directors) of the firm, some of whom are relatively young. While the early betting favoured the technicians who spend time in the lab getting their hands dirty, it would appear that, in general, there is no substitute for experience.



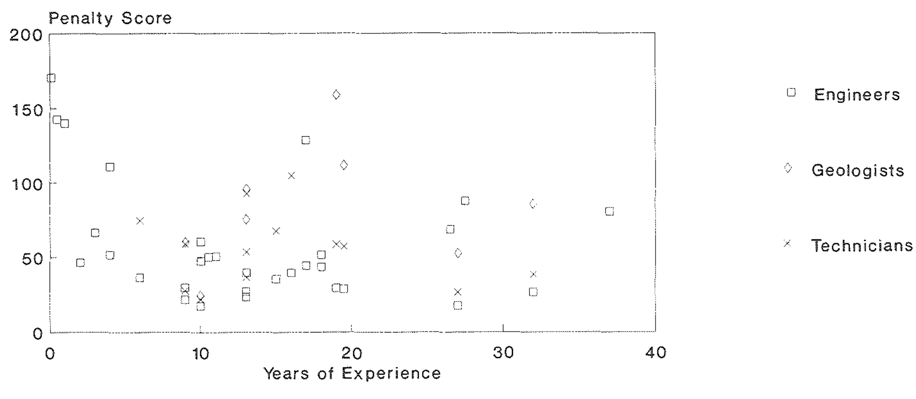








Scores
The Clay Feat



GRAVEL RASH - EDITOR'S NOTES

What an interesting exercise "The Clay Feat" was. I am sure that there are many learned practitioners who would not score as well as we lesser mortals would think...! Whilst there are many interesting points made in Stephen Jones' article, we would also like to add some comments on the data sets. Some of these are made in the blinding clarity of hindsight, others because we can do so without the risk of getting fired!

Estimate of Maximum Dry Density

(1) Professionals with limited experience can be very wide of the mark. Perhaps Don should have a chat with his junior engineers about the concept of void ratio.

(2) It would seem that people with 15 - 20 years experience get drunker more quickly, especially when they are geologists!

(3) Technicians tend not to have too many grey hairs, but they get the answers right anyway!

Estimate of Optimum Moisture Content

(1) There seems to have been an awful lot of guessing going on.

(2) Geologists don't seem to have any feeling for compaction, generally guessing too low.

(3) Perversely, there seems to have been a group of relatively senior engineers who guessed too high. They obviously need a prolonged spell at the wrong end of a compaction hammer. It's funny how doing compaction tests by hand seems to clear the mind (or were their minds on other things?)

Estimate of Plasticity Indices

1) Years ago Don Douglas introduced me to the concept of a "shotgun" plot - Well, here it is again.

(2) According to most criteria, this clay would not seem to be highly active. However, at least 25% of those surveyed would not agree (or was the whole world moving at the time - in which case we could conclude that engineers get drunk more quickly than geologists and technicians!)

(3) Did you spot the 25+ year engineer who had a material with a Linear Shrinkage value of 3% and a %fines of at least 60%. Mighty strange soils over there in the E.S. (Since this is our last issue we can make provocative statements like that - please send all your examples of expansive gravelly sands with a PI of 250 and a Linear Shrinkage of 0% to the new Editorial Panel in Victoria. We know they will be very interested!)

Estimate of Percent Fines

(1) Editorial Panel Law #1 - People really aren't used to materials without much sand in them unless they are very soft. This plot is the most interesting of all - 92% passing 75u is very high and somewhat unusual (Anyone that wants to dispute that statement, please contact Victorian Group as per above) - Nearly everyone was too low (and some far too low!)

(2) Has anyone asked D J Douglas & Partrners most senior citizen how he got this one so wrong? Shame about this result really - If he hadn't done so badly on this estimate, he would have been amongst the front runners - or was he nobbled?

Statistical analysis of the overall scores would make very interesting reading. I hope there is going to be a paper presented on these data at the next year's conference in Canberra on Probabilities and Risk - I am sure the findings will be very interesting. In view of the imminent demise of lab testing after the seminal debate in Victoria earlier this year, these new data should form an excellent basis for the development of a new random number generator to produce quantified information to pass on to clients, students, etc. The mystery of soil mechanics lives on!

STATE GROUP REPORTS

VICTORIAN GROUP

The 1992 Committee comprises:

I Pedler, (Chairman)
Dr C Haberfield, (Secretary)
R Smith
Dr W Bamford
Dr A Bennet
P McDonald
I McKenzie
J Seidel
R Sanders
K Seddon
P Thorton
Dr W Power
D Raisbeck
B Chandler
D Jordan
Dr M Kurzeme, (ex-officio member)
M Ervin, (ditto)

REPORT ON RECENT MEETINGS

October 16, 1991—W Harrison, Kinhill Engineers, I Haustofer & C Broadhurst, Vic Roads

"SOIL NAILING"

The speakers presented a lecture on the theory, design, application and construction of Soil Nails. They illustrated their talk with two case studies; the Western Ring Road - Broadmeadows Section and the Bell-Banksia Link Road.

October 21, 1991—VISIT TO CSIRO DIVISION OF GEOMECHANICS AT SYNDAL

This was a joint meeting with AusIMM. The research activities of this division were described and the meeting discussed industry's needs and CSIRO's capabilities.

November 1991 — Professor I Johnston, Monash University

E.H.DAVIS MEMORIAL LECTURE —
"GEOMECHANICS AND THE EMERGENCE OF SOFT ROCK TECHNOLOGY"

Ass. Professor I Johnston presented a repeat of his 1991 E.H.Davis Memorial Lecture. The lecture covered a wide range of subjects concerned with soft, weak and weathered rocks and represented the results of many years of research into the behaviour of these materials.The Victoria Group's annual dinner followed the lecture.

February 1992—Professor Emeritus N Janbu, Norwegian Institute of Technology.

"DEFORMATION BEHAVIOUR OF SEDIMENTS"

Professor Janbu presented an informative lecture on the above topic. He described a novel method for estimating large consolidation settlements and presented a number of case studies to illustrate its application.

March 1992—IE Aust Civil College Eminent Speaker, 1991.Murray Gillon, Works Consultancy Services (NZ)

"ASPECTS OF THE CLYDE POWER PROJECT, NZ."

Mr Gillon presented an illuminating lecture on the geotechnical aspects of the Clyde project. He explained the design problems faced and the innovative methods used to overcome these problems.

April 1992 —The Great Debate on the proposition

"THAT LABORATORY TESTING IS A WASTE OF MONEY"

Two teams of local eminent geotechnical engineers argued for and against the proposition. The team arguing for the proposition consisted of Dr Jack Morgan (Golder Associates), Mr Peter Mcdonald (Vic Roads) and Mr Brian Chandler (Maunsell). The team arguing against the proposition consisted of Dr Ian Johnston (Monash University), Dr Gary Chapman (Wagstaff Piling) and Mr Brian Ims (DJ Douglas & Partners). Dr Peter Moore (Melbourne University) officiated as adjudicator. After a reasonably close contest and to the relief of most of the audience, the team arguing against the proposition emerged victorious.

May 1992—Professors Harry Poulos & Mark Randolph and Associate Professor Ian Johnston

ALL DAY SEMINAR — "PILING—MODERN METHODS"

The speakers presented an informative, comprehensive series of lectures on pile analyses. Current techniques were critically examined and in addition a substantial amount of material (as yet unpublished) was presented. The seminar was jointly sponsored by the AGS and ACADS and attracted over 90 participants.

June 1992 - Rick Willoughby, Pasminco Ltd.

"THE INTRODUCTION OF MM130 AT PASMINCO, BROKEN HILL"

Mr Willoughby presented an interesting lecture on the new Mobile miner MM130. He explained the design process used in the development of the MM130 and described some of the problems associated with installing these machines into underground mines. This meeting was a joint meeting between AusIMM and the AGS.

FUTURE MEETINGS

8 July 1992—"Landslides in China's Water Resources Development: Case studies and Analysis" Dr Zu Yu Chen, Chinese Institute of Water Conservancy and Hydro-Electric Power Research.

12 August 1992—Student meeting at Royal Melbourne Institute of Technology (RMIT). This lecture will describe the history of projects conducted by the MMBW around Melbourne.

16 September—Seminar to mark the release of the book "Engineering Geology of Melbourne"

14 October—This lecture will describe local experience with solving soft ground geotechnical problems.

SPECIAL PROJECTS AND PUBLICATIONS

a) Engineering Geology of Melbourne: The book on the Engineering Geology of the Melbourne region is almost complete. It is due for publication in September 1992.

b) Subcommittee on Groundwater Act: A subcommittee has been formed to investigate problems concerned with the Groundwater Act and the registration of boreholes used purely for geotechnical investigation purposes. The subcommittee is to be chaired by M Ervin.

c) The Foundations and Footings Society (Vic): This society has been formed as a separate entity from the AGS and is not affiliated with the Institution of Engineers, Australia. Membership comprises professional engineers, geologists and para-professionals including council building staff. The society provides a forum for discussion of footings for houses and other related matters. The Victoria Group of AGS has a representative on the Steering Committee. A publication 'Special Provisions for Site Investigations and the Design of Residential Slabs and Footings for Victorian Conditions' was prepared in February 1992. Further sub-committee work on geotechnical, footing and superstructure matters is in progress.

SYDNEY GROUP

The 1992 Sydney Group Committee is as follows:

Bruce Walker, Chmn,	Jeffery & Katauskas
Dr Charles Gerrard, V-Chmn,	Golder Associates
Peter Andrews,	D.J. Douglas & Partners Pty Ltd
John Braybrooke,	D.J. Douglas & Partners Pty Ltd
Prof. John Carter,	School of Civil & Mining Engineering, University of Sydney
Kim Chan,	Longmac Associates Pty Ltd
Prof. Robin Fell,	School of Civil Engineering, University of New South Wales
A.Prof.Manfred Hausmann,	School of Civil Eng'g University of Technology
Paul Hewitt,	Arup Geotechnics Pty Ltd
Jack Hodgson,	J.D. Hodgson Consultants
Andrew Leventhal,	Longmac Associates Pty Ltd
Mrs Margaret McMahon,	McMahon Associates
Dr Neil Mattes,	Coffey Partners International PtyLtd
Jim Millar,	J.A. Millar & Associates Pty Ltd
Garry Mostyn,	School of Civil Engineering, University of New South Wales
Dr Tony Phillips,	Arup Geotechnics Pty Ltd
Prof. Harry Poulos,	Coffey Partners International Pty Ltd
A.Prof. John Small,	School of Civil & Mining Engineering, University of Sydney
Michael Thom,	D.J. Douglas & Partners Pty Ltd
Patrick Wong,	Coffey Partners International Pty Ltd

PROGRAMME OF RECENT MEETINGS

March 1992—Murray Gillon, Group Engineer (Geotechnical), Works and Development Services Corporation (NZ) Ltd. "Geotechnical Aspects Associated with Clyde Dam, N.Z." Joint Meeting with Civils.

April 1992—Philip Pells, Coffey Partners International Pty Ltd
"Bennelong Point Car Park"

May 1992—Professor H. G. Poulos, Chairman, Coffey Partners International Pty Ltd and Professor of Civil Engineering, University of Sydney
"Geotechnical Aspects of the Newcastle Earthquake"

June 1992 — Richard Heggie, Richard Heggie Associates Pty Ltd
"Construction Vibrations in the Urban Environment" Joint Meeting with AUCTA.

July 1992—Andrew Leventhal, LongMac Associates Pty Ltd
"Malanjkhand Copper Project, India"

FUTURE MEETINGS

12 AUGUST—"ROCK BOLTING AND ANCHORS"
Charles Gerard, Golder Associates Pty Ltd, Ross Seedsman, Australian Coal Industry Research Laboratories, Bellambi

9 SEPTEMBER—"RESEARCH AT SYDNEY UNIVERSITY"
John Carter, Director, Centre for Geotechnical Research, University of Sydney

14 OCTOBER—"PREDICTION OF RIPPABILITY OF ROCK"
Ms Fiona McGregor, University of New South Wales

11 November—Chairman's Address "SIGNIFICANT CONTRIBUTIONS TO GEOTECHNICAL ENGINEERING IN RELATION TO LOCAL PRACTICE" Bruce Walker, Jeffery & Katauskas.

FUTURE CONFERENCES / SEMINARS

"Conference on Geotechnical Management of Waste and Contamination" to be held in Sydney, 22-23 March, 1993: "Call for Papers" has closed, meanwhile conference organisation progressing well. Sub-committee Chairman: Prof. Robin Fell

"Engineering Geology of Narrabeen Group and Coal Measure Rocks of the Central Coast and Newcastle Region" Seminar has been deferred until 1994.

SOUTH AUSTRALIAN GROUP

1992 Committee Members:

Chairman	Bob Newman
Dep Chmn	John Morris
Secretary	Dr Patrick Lunn
	Paul Peter
	Peter Bayetto
	Lindsay Ballantyne
	Don Cameron
	Richard Cavagnaro
	Ed Collingham
	Ian Hosking
	Dr Peter Mitchell
	Dr Maurice Arnold
	Dr William Kaggwa
	Charles Fitzhardinge

REPORT ON RECENT MEETINGS

As usual the South Australian Group held a full programme of technical meetings, on the third Monday of each month in Chapman Hall, Institution of Engineers, 11 Bagot Street, North Adelaide.

Meetings held in 1991 and early 1992 are listed below.

Meetings have generally been well attended, notably the July '91 meeting (about 75) and the September '91 annual seminar (about 65) and the March '92 meeting with Murray Gillon which attracted about 60.

February 18, 1991—Paul Moritz, Foundation Systems,"Small Diameter Driven Piles"

March 18, 1991 - Dr Patrick Lun, PPK Consultant Engineers,"Hydraulic Fracture"

April 15, 1991 - N Holmes, Kinhill Engineers,"Underwater Geomechanics"

June 17, 1991 - Bob Newman & Ed Collingham, E & WS Dept,"River Murray - Salt Interception Schemes"

July 15, 1991 - Don Cameron, University of South Australia "AS 2870 Residential Footings Code" (combined meeting with SA Footings Group and SA Structural Group)

August 19, 1991 - Dr Peter Mitchell, PPK Consultant Engineers, "The Collapsible Soil Problem"

September 19, 1991—ANNUAL SEMINAR—"PILED FOUNDATIONS"
Roman Washyn, Dept of Road Transport. Park Terrace Railway Overpass—Prediction Vs Performance
Ian Hosking, Coffey International. Pile Driving Vibration in Sands
Dr Peter Mitchell, PPK Consultants.Piled Raft Design
Slav Tchepak, Frankipile Australia.Recent Advances in Piling
Prof HG Poulos, Coffey Partners International.Piling in Shrinking and Swelling Soils
Copies of the Proceedings are available on enquiry.

October 21, 1991—Dr Peter Dillon, Dr Santo Ragusa, Centre of Groundwater Research SA, "Microbiological Clean up of Contaminated Sites.

November 18, 1991—Visitors Night Annual Dinner,"Environmental Geomechanics"

February 17, 1992—Dr Brian Richards, CSIRO,"John Jaeger Memorial Lecture" - a repeat of the award lecture first presented at the 6th ANZ Conference on Geomechanics, in Christchurch in February 1992.

March 16, 1992 - Murray Gillon,"Geotechnical Aspects associated with Clyde Dam, NZ."—joint meeting with HYDSOC.

April 27, 1992—Kevin Mills, University of SA,"Application of the Physical Chemistry of Swelling Soils to the Prediction of Movements."—Jae Li, University of SA,"Side Friction on Beams in Swelling Soils"

May 18, 1992—Ian Hosking, Coffey International "Geotechnical Investigation for Pt. Stanvac Single Buoy Mooring and Pipeline."

June 15, 1992—Lindsay Ballantyne,"Design and Testing of Piled Foundations—Port Augusta Power Station."

July 20, 1992—Bob Newman, E & WS Dept. "Chowilla Salinity Mitigation Proposals."

August 17, 1992—Dr Peter Mitchell, PPK Consultant Engineers,"Case Studies of Footing Failures"—a joint meeting with the Footings Group.

September 21, 1992—ANNUAL SEMINAR - "Environmental Geomechanics"

October 19, 1992—William Kaggwa, Don Cameron and students.Research at University of Adelaide & University of SA.

November 16, 1992—Dept of Road Transport, S.A.,"Quality Management in Geotechnical Engineering."

QUEENSLAND GROUP

The Queensland Committee for 1992 includes a few new faces this year with good representation from the geological and geotechnical consulting community. The Committee comprises:

Robert Morphet (Chairman)	Golder Associates Pty. Ltd
Alan Moon (Vice-Chairman)	Coffey Partners International Pty. Ltd
Bruce White (Secretary)	D. J. Douglas & Partners Pty.Ltd
John Beal	Engineering Geology Services Pty. Ltd
Gavin Blakey	B.C.C. Materials Section
Bevan Boyce	Queensland University of Technology
Michael Brock	Blain Johnson Pty. Ltd
Scott Fidler	Golder Associates Pty. Ltd
Joe Gough	Insite Geology Pty. Ltd
Andrew Middleton	Hollingsworth Dames & Moore Pty.Ltd
John Simmons	BHP Engineering
Peter Stocker	Golder Associates Pty. Ltd
Paul Wallis	Arup Geotechnics Pty. Ltd
K.Y. Wong	University of Queensland
Michael Yau	Soil Surveys & ExplorationPty. Ltd

REPORT ON RECENT MEETINGS

February 1992—Scott Fidler, Golder Associates

"SOIL REINFORCEMENT"

Scott detailed results and conclusions drawn from research work carried out for his Masters degree. His presentation included a number of design philosophies for extensible reinforcements based on research at the Q.U.T.

March 1992—Murray Gillon

"CLYDE DAM"

I am sure that all State Groups were presented with a very interesting and informative talk on a problem emanating from the " The Shakey Isles".

April 1992—Maurie Philp, Coffey Partners International

"LITIGATION"

Maurie presented some recent litigation cases in which he had been involved and gave his wise and philosophical thoughts on "what went wrong". This talk was videoed for possible distribution after we "bleep" out a few of Maurie's colourful expletives.

MAY 1992—SYMPOSIUM— "SAFETY IN EXCAVATIONS"

A group of guest speakers presented various aspects on the necessity and requirements for shoring excavations. The speakers included representatives from the following organisations:

Division of Workplace Health & Safety
National Safety Council of Australia
Civic & Civic
MFM Trench Shoring Systems Pty. Ltd
Wreckair Pty. Ltd
Shorco Hire Pty. Ltd
Brisbane City Council
Golder Associates Pty. Ltd

The need for adequately designed shoring in all situations was stressed and backed up by dramatic videos of the dangers of entering unshored excavations.

June 1992—Russell Cuthbertson, Geological Survey of Queensland.

"FACTORS AFFECTING EARTHQUAKE INTENSITIES"

This was a joint meeting with the Queensland Division of the Australian Geological Society.

Russell presented background information on seismic (earthquake) theory and the relationship of earthquake events to variations in geology in particular sediments. Historical examples as well as current modelling were outlined and the generation of seismic risk maps discussed.

FUTURE MEETINGS

Technical presentations proposed for the remainder of 1992 include the following:

July 23, 1992

"DIAPHRAGM WALL/BARRETTE CONSTRUCTION"

Dr Tony Phillips, Arup Geotechnics Pty. Ltd Peter Openshaw, Bachy

Peter will describe construction procedures, on-site quality control and illustrate examples. Tony will present an overview of the design of the barrette foundations for the ARC Cement Silo at Newcastle.

August 20, 1992

DINNER MEETING

The venue, invited speaker and topic are still to be finalised. Hopefully a memorable occasion as all previous dinner meetings have been.

September 3, 1992

"CENTRIFUGE MODELLING IN GEOMECHANICS WITH APPLICATIONS IN MINING"

Professor Mark Randolph, University of Western Australia
Our knowledge of "fuging" in Queensland is quite limited, so hopefully Mark can enlighten us on what we are missing out on.

October 22, 1992

"E.H. DAVIS MEMORIAL LECTURE"
Professor Ian Johnston.

November 19, 1992

ANNUAL GENERAL MEETING

The Queensland Group welcomes suggestions from all Queensland members for topics for technical presentations in 1993. Please forward your thoughts to any members of the Committee.

TASMANIAN GROUP

REPORT ON RECENT MEETINGS

September 1991—Dr Ross Large, Director of the Key Centre for Ore Deposit and Exploration Studies—CODES, University of Tasmania.

"THE MINERAL POTENTIAL OF WESTERN TASMANIA."

Dr Large descibed the distribution of mining areas in Western Tasmania and the history of their development.

He identified two stages, i.e. the development of surface deposits between 1860 and 1930 and the development of sub-surface deposits between 1960 and 1990. The latter developments resulted from applying new sub-surface investigation techniques. He discussed the current value of ore deposits in the region and suggested that a new major mining project would be required every five years to maintain the current level of mining activity.

Dr Large presented details of the operation of CODES and its objectives. The organisation is generally financed by the mining industry. Its activities are spread throughout Australia. In Tasmania research is currently centred on the Mount Read vulcanics which contain significant metal sulphides.

Dr Large concluded his address with a discussion on the environmental impact of mining activity and showed how modern methods could reduce such impact to virtually insignificant levels.

November 1991—Ivan Hausdorfer, Vic Roads, Melbourne

"SOIL NAILING"

Mr Hausdorfer described soil nailing as a type of passive reinforcement of soil slopes which enabled the construction of steeper batters. This method of slope stabilisation had been developed in France during the 1970s and is now also used in other European countries. Large scale tests had been carried out in France, the UK and the USA and had identified three modes of failure, ie. breakage of the soil nails, slippage of the nails and failure due to excessive height.

In the design of soil nailed slopes, a number of factors had to be considered including external stability, internal stability, nail capacity, shotcrete failure, allowable displacement, drainage, etc. In the overall design aesthetics should also be considered.

Mr Hausdorfer concluded by presenting details of failure analysis carried out on soil nailed slopes. His address was illustrated with a series of slides showing the use of soil nailing techniques at two projects in Victoria.

February 1992—Dr John Hutchinson, Imperial College, London

"LANDSLIDES IN PERU"

Dr Hutchinson passed through Hobart on his way to New Zealand for the International Landslide Conference and kindly agreed to present a talk on his experiences in South America to members of the Society.

Dr Hutchinson presented an illustrated address covering aspects of two major landslide events in the Andes Mountains plus details of a slope stabilising project at the Tablachaca Dam on the Mantaro River. In one of the landslides, approximately 1500M cu.m of material, mainly Permian mudstone, had slid into the Mantaro River valley, 35km downstream of the Tablachaca Dam. The landslide created a temporary embankment that blocked the river for about 40 days. When the fill was eventually overtopped the flow downstream was estimated to have peaked at 10000 cu.m/s. The flood wave caused by this event was recorded well downstream along the Amazon River in Brazil. The slip material had been inspected prior to overtopping. It consisted mainly of gravels with little clay, c'=0, phi'(peak)~33 degrees, phi'(res)~25 degrees.

At the Tablachaca Dam it had been noticed that the right bank upstream and adjacent to the dam was being undercut due to the continuous operation of one of three bottom sluice gates in the dam. These gates had to be operated continuously to prevent siltation of the reservoir. The sluice flow caused the formation of a back eddy which destabilised the toe. Remedial works at the site included the construction of a stabilising berm plus soil anchors in the potential slide material.

March 1992 - Murray Gillon, Works Consultancy Services, Wellington, New Zealand

"GEOTECHNICAL PROBLEMS ASSOCIATED WITH THE CLYDE DAM"

Mr Gillon presented an overview of the reservoir stabilising works which are being carried out prior to the filling of the Clyde Dam reservoir. In his talk, Mr Gillon showed details of the investigation work which was carried out at the damsite and at a series of recent (in a geological sense) landslide areas above the new reservoir. Substantial stabilising works had been put in place at a number of sites to reduce the risk of failure to acceptable limits. An extensive network of instrumentation had been installed to monitor both the dam and the reservoir banks during the impounding operation.

May 1992—Dr Fred Baynes, Consulting Geologist, Hobart

"MANAGEMENT OF THE ROSETTA LANDSLIDE"

Dr Baynes presented a detailed assessment of the Rosetta Landslip area which is located in the Municipality of Glenorchy, north of Hobart. He showed details of the monitoring work which was being carried out to ascertain the nature and extent of the slip zone. Management of the slip zone was found to be costly. The landslip had had a profound effect on the local community not only in monetary terms but also socially. The need for effective communications of technical matters with the affected residents was stressed.

WESTERN AUSTRALIAN GROUP

The 1992 Western Australian Group Committee is as follows:

Ian Smith, Chairman
Prof. Mark Randolph, Secretary
Trevor Osborne
Martin Fahey
Peter Lilly
Colin Bradbury
Tony Abbs
Charles Waterton
Geoff Cocks
Peiter Zwaan
Andrew Cray
Steve Brice

PROGRAMME OF RECENT MEETINGS

13 February 1992—Prof. John Booker, Sydney University

'ANALYTICAL METHODS IN GEOMECHANICS'

The theme of Professor Booker's talk was the role which analytical methods can play in geomechanics. He showed that what may at first sight appear to be a very complex problem can often be simplified and idealised to the extent that an analytical solution can be found. This process is in itself of great value as it helps in identifying the essential features of the problem.

Having achieved this idealisation, some problems could then be completely solved analytically, though sometimes a combination of analytical and numerical methods were required.

The most powerful message which the speaker conveyed to the audience was that even with the ready availability of very powerful finite element or boundary element packages, some attempt should always be made to arrive at an analytical solution, no matter how much idealisation was required.

Even if finite element or similar analysis was still believed necessary, the amount of such analysis would be reduced, and very often this effort would be directed at further clarifying the areas of concerns highlighted by the analytical solution.

24 March 1992 - Murray Gillon, New Zealand Works Consultancy Services

'GEOTECHNICAL PROBLEMS ASSOCIATED WITH THE CLYDE DAM'

Murray Gillon was the IEAust Eminent Speaker for 1992. A report on his talk can be found elsewhere in this issue.

14 April 1992—Trevor Osborne, Osborne Geotechnical

'RESIDUE AREA GROUTING'

For a number of years Trevor Osborne has consulted to Alcoa of Australia Ltd and worked closely with Alcoa personnel on the reduction of losses of caustic liquor from tailings areas at Kwinana. Original residue areas were constructed on permeable sandy formations with containment provided by sand embankments and lined with clay blanket and an overlying sand under-drain. Residue placement has now proceeded to depths of 20 to 30 metres. Monitoring around the residue areas has detected some losses of caustic liquor from the facility and much effort has been put into locating and sealing the sources of the leakage.

The talk described the methods of leak location which now routinely include piezometric head survey of the underdrains, sampling and property analysis of liquor in vicinity of suspected leakage and the use of electrical conductivity measurement. Once leakage is located, sealing is achieved by injection of chemical grout into the sand blanket.

The speaker described the equipment and methods employed to realise this sealing under greater than 20 metres of residue deposits and showed a number of slides of the work in progress.

12 May 1992—Dr Martin Fahey, University of Western Australia.

'USE OF THE SEISMIC CONE AND PRESSUREMETER TESTS FOR SETTLEMENT ANALYSIS'

The starting point for the talk was that the stress-strain behaviour of practically all soils is highly non-linear, even in the 'elastic' range. This means that the appropriate value of secant modulus to use in a deformation calculation depends upon the shear stress level at each location. Therefore, even for a homogeneous soil layer, the appropriate stiffness value will vary with location relative to the loaded area. Rather than attempting to define how to choose the appropriate secant stiffness value for each location, the speaker suggested that a more logical approach is to accept that the response is non-linear and to put effort into devising methods of defining the precise stress-strain curve for each site.

The speaker then went on to show how this was being done for sand. A non-linear elastic, Mohr-Coulomb plastic model was proposed. The 'elastic' part is similar to the usual hyperbolic model but with two additional parameters to allow the model to be matched with experimental data:

$$\frac{G}{G_0} = \left[1 - f\left(\frac{\tau}{\tau_{max}}\right)^g\right]$$

where G is the secant modulus, G_o is the 'small strain' shear modulus, τ and τ_{max} are the mobilised shear stress and the maximum shear stress (i.e. the current shear strength). The parameters f and g are empirical parameters — f dictates the strain to failure and g controls the shape of the curve up to failure.

The method proposed for calibrating the model consists of carrying out seismic cone tests to provide the value of G_o at the in situ stress state and the parameters f and g are obtained by using the model with a finite element cavity expansion program and varying f and g to match the shape of the unloading-reloading curves in self-boring pressuremeter tests. This process was demonstrated using data from a site in Perth. The talk finished with an outline of seismic cone testing, a description of the equipment developed at UWA in conjunction with the Engineering Research Station (Water Authority of Western Australia) and a sample of the types of results being obtained.

A vote of thanks was proposed by Mr Chris Potulski.

9 June 1992— David Elias, Dames & Moore

'SEISMIC ANALYSIS OF EARTH STRUCTURES'

By world standards, Western Australia is not particularly seismically active. However, it is still necessary to assess the design and performance of earth structures particularly water and tailings dams - when subjected to seismic loading conditions.

David Elias pointed out that although a lot had been published on seismic analysis, there was not a concise approach applicable to earth structures. A procedure for the simple seismic analysis of such structures was presented which had been prepared by reviewing the literature. The procedure reflects the current state of practice in California but takes account of Australian conditions.

25 June 1992—Steve Brice, Geological Survey

GEOLOGICAL DATA BASE FOR THE PERTH CENTRAL BUSINESS DISTRICT'

The increase in building activity in the Central Business District (CBD) of Perth over the last decade had lead to a large volume of geological and geotechnical data being available from the numerous site investigation studies that had been carried out. The vast quantity of factual data available is not generally in a form that is useful to geotechnical engineers, structural or design engineers or town planners.

Steve Brice outlined how the Geological Survey of Western Australia has established a trial database of geotechnical information as a pilot project for a larger scale database of this type. The pilot project involved the acquisition of a large volume of data from a variety of digital and non-digital sources. He described how a Geographic Information System (GIS) approach is being adopted to permit a thorough analytical investigation through interrogation and manipulation of the various stored datasets.

PROGRAMME FOR REMAINDER OF 1992

23 JULY—"MINING TECHNOLOGY" Speaker: Gary Lye, CRA, ATD

11 AUGUST— "LIQUEFACTION OF TAILINGS DAMS" Speaker: Prof. P.K.Robertson, University of Alberta, Canada

8 SEPTEMBER - "INVESTIGATION TECHNIQUES IN CONTAMINATION" Speakers: Mike Hillman, Coffey International Peiter Zwaan, Golder Associates

13 OCTOBER— "BLASTING" Speaker: Trevor Little, School of Mines

20 OCTOBER —"QV1 PROJECT—FOUNDATION SYSTEM" Speakers: John Ryan, Airey Ryan & Hill Denis Smith, Soil & Rock Engineering

10 NOVEMBER - "INSITU TESTING OF SOIL" Speaker: Prof. Peter Robertson

KALGOORLIE GROUP

In 1990 several mining and geotechnical engineers based in the Kalgoorlie area formed a group called the Goldfields Geotechnical Group (GGG). The purpose of the group was to promote geotechnical science and to provide a forum for the exchange of ideas in the field of Rock and Soil Mechanics. The group was lead by D Fotakis and P Loubser and in 1991 organised seven meetings during which internal and external presenters lectured on new solutions and achievements in mining rock mechanics.

During the GGG meeting on 6 March 1992 members of the GGG indicated their willingness to join the AGS as a local group. As a result on 7 April 1992 a meeting of the group unanimously voted to transform the Goldfields Geotechnical Group into the Kalgoorlie Group of the Australian Geotechnical Society. The following committee was elected:

T Szwedzicki, Chairman	WASM Tel:(090)805172 Fax:(090)805151
D Fotakis Co-Chairman	KCGM
TN Little,Secretary	WASM Tel:(090)805155 Fax:(090)805151
G Auld, Member	WMC
P Loubser, Member	WMC

The group consists of eleven AGS full paying members and twelve supporting members who are expected to join in the near future. Anyone interested in the activities of the group are invited to contact Trevor Little at the West Australian School of Mines Tel: (090) 80 5155.

PROGRAMME FOR 1992:

6 February—'WATER TABLE MEASUREMENT USING PIEZOMETERS IN OPEN PIT MINES' Speaker: Colin Visca, SINCO

7 March—'GEOTECHNICAL INSTRUMENTATION AND CABLE BOLTING' Speaker: Doug Minchin, Rock Engineering

8-10 June—'WESTERN AUSTRALIAN CONFERENCE ON MINING GEOMECHANICS' Organiser: Western Australian School of Mines

24 June— 'RADIO IMAGING IN MINING' Speaker: Scott Thompson, Mineral Exploration Technical Services

28 Sept-2 Oct—'SCHOOL ON NUMERICAL MODELLING IN MINING GEOMECHANICS' Organiser: WASM/CSIRO

GEODIARY

CONFERENCES, COURSES, SEMINARS, SYMPOSIA, WORKSHOPS, ETC.

Brief details of conferences, courses, seminars, symposia, workshops, etc will be entered in Geodiary without charge as a service to members of the Society. Advertisements giving more prominence and carrying greater detail may be inserted in any issue of Australian Geomechanics.

NOV 2-5, 1992

Perth, Western Australia

INTERNATIONAL BAUXITE TAILINGS WORKSHOP

Topics: Classification, dewatering and washing processes; Slurry transportation and distribution techniques; Material properties and design of storage facilities; Operational practices; Environmental monitoring and management; & Alternative uses for bauxite residues and storage areas. This international workshop will provide an update on bauxite tailings management from the process to the final storage or alternative use.

Milena di Russo, Workshop Secretary, Bauxite Tailings Workshop, PO Box 265, Hamilton Hill, WA, 6163 Australia. Tel: (09) 434 2886. Fax: (09) 418 4980.

NOV 3-5, 1992

Rio de Janeiro, Brazil

1st BRAZILIAN CONFERENCE ON SLOPE STABILITY

Topics: Various topics with particular focus on the tropical and densely populated areas of Rio de Janeiro. **Language:** Portuguese.

ABMS/COBRAE-Av. Rio Branco 124-18oandar,CEP 20042-centro, Rio de Janeiro-RJ. Tel:(021) 221 6177-R.178 or 108. Fax: (021) 580 1026 or (021) 511 1546.

NOV 6-7, 1992

Tokyo, Japan.

INTERNATIONAL SYMPOSIUM ON RECENT CASE HISTORIES OF PERMANENT GEOSYNTHETIC-REINFORCED SOIL RETAINING WALLS

Prof. Fumio Tatsuōka, the Institute of Industrial Science, University of Tokyo, 22-1, Roppongi 7-chome, Minato-ku, Tokyo 106, Japan.

NOV 11-13, 1992

Fukuoka, Japan.

INTERNATIONAL SYMPOSIUM ON EARTH REINFORCEMENT PRACTICE. (IS Kyushu '92)

Topics: Materials; Analysis, design & testing methods; Construction practices; Monitoring systems. **Language:** English.

Secretariat of IS Kyushu '92, Prof. Hidetoshi Ochiai, Dept of Civil Engineering (Suiko), Kyushu University, Hakozaki, Fukuoka 812, Japan. Tel:(092) 641 1101 ex 5212 or 5232. Fax: (092) 641 5195.

NOV 17-22, 1992

Wahun, China.

INTERNATIONAL SYMPOSIUM ON HYDRAULIC RESEARCH IN NATURE AND LABORATORY.

Topics: River dynamics; Hydraulics for structures and hydromachines; Environmental hydraulics; Cooling water systems; Navigation hydraulics; Ground water hydraulics.

Prof. Liu Daming, Yangtze River Scientific Research Institute, 23 Huang Pu Road, Wuhan, 430010, China.

Nov-Dec, 1992

Bangkok, Thailand.

GEOTECH 1992

This year Geotech 92 includes workshops and courses as follows:

Nov 23-26,1992

Workshop on COMPUTER AIDED DESIGN IN GEOTECHNICAL ENGINEERING

Nov 30-Dec 4, 1992

Symposium on PREDICTION vs PERFORMANCE IN GEOTECHNICAL ENGINEERING and

Dec 7-11, 1992

Workshop on APPLIED GROUND IMPROVEMENT TECHNIQUES

Prof. A.S. Balasubramamiam, Geotechnical Engineering Division, Asian Institute of Technology, GPO Box 2754, Bangkok 10501, Thailand. Fax:(662) 524 5523.

DEC 7-11, 1992

New Delhi, India.

REGIONAL SYMPOSIUM ON ROCK SLOPES.

Themes: Geotechnical parameters, geological aspects, investigations and data interpretation; Drilling and blasting techniques - innovative approaches; Slope stability analysis; Rock anchoring, other stabilising methods and drainage; Slope monitoring and instrumentation; Special problems of opencast mining. **Abstracts:** Dec 31, 1991. **Papers:** May 31, 1992. **Language:** English.

C V J Varma, Organising Secretary, Regional Symposium on Rock Slopes - India, The Committee of the International Society for Rock Mechanics, Plot No 4, Institutional Area, Off Malcha Marg, Chanakyapuri, New Delhi - 110021, India. Tel:91 11 301 5984. Fax:91 11 301 6347.

FEB 10-12, 1993

Canberra, Australia.

CONFERENCE ON PROBABILISTIC METHODS IN GEOTECHNICAL ENGINEERING.

Topics: Probabilistic techniques in geotechnical engineering; Probabilistic design of slopes, foundations and other geotechnical structures; Modelling of soil properties; Other aspects of probabilistic methods in geomechanics. **Abstracts:** Mar 25, 1992. The conference will be preceded by a two day workshop on 8-9 Feb 1993 presented by invited speakers covering various aspects of geotechnical reliability.

Dr K.S. Li, Department of Civil & Maritime Engineering, University College, University of New South Wales, ADFA, Campbell, ACT 2600. Tel:(06) 268 8329. Fax:(06) 268 8337.

FEB 16-18, 1993

Wollongong, NSW, Australia.

INTERNATIONAL CONFERENCE ON ENVIRONMENTAL MANAGEMENT - GEO-WATER AND ENGINEERING ASPECTS.

Topics: Risk and reliability in geomechanics and water engineering; Water quality modelling of catchments, rivers, reservoirs and estuaries; Soil erosion and sediment transport; Water quality in water supply and resource management; Slope stability and landslide management including urban, riverbank and reservoir slope stability; Dams and reservoirs; Solid waste, urban storm water and waste water management; Mine water, mine drainage and rehabilitation; Urban hydrology; Flood management.

Dr M Sivakumar, Department of Civil & Mining Engineering, University of Wollongong, Locked Bag 8844, South Coast Mail Centre, NSW, 2521 Australia. Fax:61 42 213238. Tel: 61 42 213055.

MAR 22-23, 1993

Sydney, NSW, Australia.

CONFERENCE ON GEOTECHNICAL MANAGEMENT OF WASTE AND CONTAMINATION.

Topics: Site investigation and monitoring techniques for waste disposal and contaminated sites; Groundwater contaminant flow in soil and rock; Legislative controls and "safe" contaminant levels; Site remediation and chemical cleanup; Ground modification techniques, eg clay and geomembrane liners, dynamic compaction, vibroflotation, grouting; Foundations for reclaimed landfill sites; Design of landfills and their rehabilitation; Mine tailings disposal and rehabilitation, eg prediction of properties, impact of operation phase and long term seepage, safe contaminant levels, seepage minimisation techniques.

Conference organisation enquiries to: The Conference Manager, Conference on Geotechnical Management of Waste and Contamination, Tel:(06) 2706 559. Fax: (06)2732 918.

APR 5-7, 1993

Istanbul, Turkey.

INTERNATIONAL SYMPOSIUM - ASSESSMENT AND PREVENTION OF FAILURE PHENOMENA IN ROCK ENGINEERING.

Themes: Failure phenomena and there mechanisms -model tests -surface structures -underground openings; Theoretical Approaches -strain localisation -failure mechanics -damage mechanics -plastic and visco-plasticity theory; Numerical approaches -finite element -boundary element -other methods; Case studies -slope and open pit mines -foundations -dams -tunnels -underground caverns -underground mining.

Prof. Gunhan Pasamehmetoglu, Middle East Technical University (ODTU), Dept of Mining Engineering, 06531 Ankara, Turkey. Tel: 90 (4) 223 71 00 Extn 2654. Fax: 223 30 54.

APR 6-8, 1993

Paris, France

INTERNATIONAL CONFERENCE ON THE ENVIRONMENT AND GEOTECHNICS

Topics: Legislative and legal aspects; Ground water and sub-soil protection; Site decontamination, treatment and land reclamation; Recognition and construction in reclaimed areas.

Prof. F Schlosser, L'Ecole Nationale des Ponts et Chausees, Paris, France.

APR 19-22, 1993

Amsterdam, The Netherlands.

INTERNATIONAL CONGRESS "OPTIONS FOR TUNNELLING" 1993.

Topics: Research and new developments on site investigation; Design and construction of tunnels in soft ground and rock; Submerged floating tunnels. **Language:** English. **Abstracts:** Feb 1, 1992.

OPT 1993, c/- Congress Office KIVI, PO Box 30424, 2500 G.K. The Hague, The Netherlands. Tel:31 70 391 9890. Fax:31 70 391 9840.

MAY 2-6, 1993

Ontario, Canada

SIXTH CONFERENCE ON SHOTCRETE FOR UNDERGROUND SUPPORT

Topics: Design; Dry mix and wet mix processes; Additives; Reinforcement; Robotics and shotcreting; Soil nailing and shotcrete.

Prof. D.F. Wood, University of Toronto, Sudbury, Ontario, Canada. Fax: 705 673 6532.

May 4-8, 1993

Singapore

11th SOUTHEAST ASIAN GEOTECHNICAL CONFERENCE

Theme: Soft Ground Engineering. **Topics:** Soil Characterisation and testing; Engineering geology; Slope Stability and landslides; Ground improvement; Shallow and deep foundations; excavation and buried structures; environmental geotechnics. **Language:** English.

Conference Manager, 11 SEAGC, 150 Orchard Rd, #07-14 Orchard Plaza, Singapore. Tel: (65) 7332922. Fax:(65) 2353530.

MAY 26-28, 1993

Copenhagen, Denmark,

SPECIALIST SYMPOSIUM ON LIMIT STATE DESIGN IN GEOTECHNICAL ENGINEERING.

Topics: Existing practice in the use of LSD; Major problems in its use; Interaction between design in structural and geotechnical engineering.

Dr Niels Krebs Ovensen, Director, Danish Geotechnical Institute, 1 Maglebjergveg, PO Box 119, DK-2800, Lyngby, Denmark.

JUN 1-4, 1993

Ghent, Belgium

2nd INTERNATIONAL SEMINAR-DEEP FOUNDATIONS ON BORED AND AUGER PILES.

Topics: Design, installation and monitoring; In-situ testing; Pile-raft interaction; Settlement; Case studies.

Secretariat of B.A.P.I.I., Laboratory of Soil Mechanics, Prof. W.F. Van Impe, Grostesteenweg-Noord 2, 9052 Zwijnaarde, Ghent, Belgium. Tel: 32 91 64 5723 Fax: 32 91 64 5849.

JUN 1-6, 1993

St Louis, Missouri, USA.

3rd INTERNATIONAL CONFERENCE ON CASE HISTORIES IN GEOTECHNICAL ENGINEERING.

Case History Themes: Foundations; Slopes, dams and embankment; Geotechnical earthquake engineering; Man-made vibrations; Retaining structures and deep excavations; Geological engineering and rock engineering; Soil improvement, grouting, geosynthetics, dynamic compaction, vibroflotation, blasting and other methods; Forensic engineering "Where things went wrong"; Geo-economy - adequate geotechnical solution; Geotechnical and hydrological management of solid, hazardous and low level radioactive wastes; Geotechnical and hydrological remediation of solid, hazardous and low level radioactive wastes; Liner and final cover for solid, hazardous and low level radioactive waste management facilities; New solutions to traditional geotechnical problems. Case histories dealing primarily with settlement prediction and performance will be referred to ASCE settlement conference, Spring 1994.

Shamsher Prakash, Chairman, Conference on Case Histories in Geotechnical Engineering, Civil Engineering Department, University of Missouri-Rolla, Rolla. MO 65401-0249, USA. Tel: 1 314 341 4489. Fax:1 314 341 4729.

JUN 2-8, 1993

Kobe, Japan.

KIGForum '93. 2nd KANSAI INTERNATIONAL GEOTECHNICAL FORUM ON COMPARATIVE GEOTECHNICAL ENGINEERING.

Topic: Excavation. Design, construction and performance of all types of excavation; Geotechnical problems with excavation in urban areas. **Language:** English.

Prof. Daizo Karube, Dept of Civil Engineering, Kobe University, Nada, Kobe, 657 Japan. Tel:81 78 881 1212 (ext 5178). Fax:81 78 861 0779.

JUN 9-11, 1993

Montpellier, France.

GEO CONFINE '93

Themes: Natural geological barriers; Improvement of containment with treated geomaterials; Cover and surface isolation for disposal sites; monitoring systems and safety of confinement; New confinement concepts. **Languages:** English and French.

Michel Barres, BRGM - Department "Environment", BP 6009, 45060 ORLEANS CEDEX, France. Tel:(33) 38 64 3414. Fax:(33) 38 64 3013.

JUN 21-22, 1993

Kalgoorlie, Western Australia.

AUSTRALIAN CONFERENCE AND WORKSHOP ON GEOTECHNICAL INSTRUMENTATION AND MONITORING IN OPEN PIT AND UNDERGROUND MINING

Topics: Stability of mining excavations; Geotechnical input into mine design; Prediction of rock mass failure; Interpretation of monitoring results; New solutions and equipment. **Abstracts:** Dec 15, 1992. **Papers:** April 1, 1993.

Contact: Dr Tad Szwedzicki, Department of Mining Engineering and Mine Surveying, Western Australian School of Mines, PO Box 597, Kalgoorlie, WA, 6430. Tel:(090) 805 172. Fax:(090) 805 151; or

Dr C.F. Swindells, Dept of Minerals and Energy, 100 Plain St, East Perth, WA, 6004. Tel:(09) 222 3597. Fax: 222 3633.

JUN 21-24, 1993

Lisbon, Portugal.

EUROCK '93 - ISRM INTERNATIONAL SYMPOSIUM

Themes: Modelling in safety evaluation; Influence of the environment in rock engineering; Stability of large underground structures; Contribution of failures and incidents to the progress of rock engineering. **Languages:** English, French and German. **Abstracts:** Sep 30, 1992. **Papers:** Feb 28, 1993.

Luis Ribeiro e Sousa, EUROCK '93, c/o LNEC, Av.do Brasil, 101, P-1799 Lisbon Codex, Portugal. Tel:(351) 1 8482131. Fax:(351) 1 897660.

JUN 25, 1993

Lisbon, Portugal.

INTERNATIONAL WORKSHOP - SCALE EFFECTS IN ROCK MASSES

Themes: Deformation and strength of rock masses; Internal stresses in rock masses; Hydraulic properties of rock masses. **Language:** English. **Abstracts:** Sep 30, 1992. **Papers:** Feb 28, 1993.

Antonio Pinto da Cunha, Int Workshop on Scale Effects, c/o LNEC, Av.do Brasil, 101, P-1799 Lisbon Codex, Portugal. Tel:(351) 1 8482131. Fax:(351) 1 897660.

JUN 26-JUL 1, 1993

St Johns, Newfoundland.

4th CANADIAN MARINE GEOTECHNICAL CONFERENCE

Topics: Foundation analysis; Case histories; Ice-seabed interaction; Soil properties; Centrifuge applications; Instrumentation; Codes and standards; In-situ measurements; International projects; Site investigations; Environmental geotechnics; Monitoring.

C-CORE, Memorial University of Newfoundland, St Johns, NF, A1B3X5. Tel:(709)737 8354. Fax:(709)737 4706.

JUN 28-JUL 1, 1993

Anchorage, Alaska.

INTERNATIONAL CONFERENCE ON FROST IN GEOTECHNICAL ENGINEERING

Topics: Theory pertaining to prediction of frost penetration and thermal degradation of frozen layer; Application to design and construction; Case histories.

Dr Arvind Phukan, Chairman Organising Committee, School of Engineering, University of Alaska Anchorage, 3211 Providence Drive, Anchorage, AK 99508-8096, USA.

JUL 1993

Bolton, England.

EUROPEAN SYMPOSIUM ENVIRONMENTAL GEOTECHNOLOGY (ENGINE '93)

Theme: Waste disposal by landfill.

Prof. R.W. Sarsby, Bolton Institute of Higher Education, School of Civil Engineering, Dean Rd, Bolton, England. Tel: 0204 28851. Fax: 0204 399074.

JUL 1993

France.

INTERNATIONAL SYMPOSIUM ON STORAGE AND CONFINEMENT OF TOXIC WASTE IN GEOLOGICAL MEDIA.

Sponsored by IAEG.

JUL 12-16, 1993

Birmingham, UK.

2nd INTERNATIONAL CONFERENCE ON MICROMECHANICS OF GRANULAR MEDIA - "POWDERS AND GRAINS 93".

Topics: Particle assemblies; Particle interactions; Quasi-static deformation; Rapid granular flow; Aggregation/segregation; Fracture/fragmentation; Particle solids. **Abstracts:** Sep 1, 1992.

Dr Colin Thornton, Dept of Civil Engineering, Aston University, Aston Triangle, Birmingham B4 7ET, England. Tel:(44) 21 359 3611 ext 4364. Fax:(44) 21 333 3389.

Aug 11-15, 1993

Beijing, China.

INTERNATIONAL CONFERENCE ON GEOSCIENCE IN URBAN DEVELOPMENT (Landplan IV)

Themes: General review of geoscience in urban development; Instability in large cities - natural disasters; Instability in large cities - geo-environment change and induced geohazards; Problems in reconstruction of large cities; Pollution and hazardous waste disposal in large cities; Engineering geological and geo-environmental investigation for urban planning and construction; Chinese megacities; World megacities.

Prof. Wang Sijing, Chairman LANDPLAN IV, Institute of Geology, Academia Sinica, PO Box 634, Beijing, China 100029. Tel:86 1 202 7766. Fax:86 1 491 9140.

AUG 16-18, 1993

Kingston, Ontario, Canada.

3rd INTERNATIONAL SYMPOSIUM ON ROCKBURSTS AND SEISMICITY IN MINES.

Topics: Mechanics of seismic events and rockbursts; Monitoring of seismicity and seismic networks; Rock mass characterisation in seismically active mines; Rockburst hazard mitigation and ground control; Induced seismicity. **Abstracts:** JUL 1, 1992.

Dr R Paul Young, Dept of Geological Sciences, Queen's University, Kingston, Ontario, Canada K7L 3N6. Tel:613 545 6171. Fax:613 545 6512.

AUG 23-26, 1993

Kingston, Ontario, Canada.

INTERNATIONAL CONGRESS ON MINE DESIGN.

Theme: Mining into the 21st Century. **Topics:** Computer applications; Backfill technology; Microseismic technology; Mine automation and material handling; Blasting technology; Open pit technology; Underground support design; Mine sequencing; Mine ventilation; Mine dewatering; Instrumentation technology. **Language:** English and French.

Dr Peter Bawden, International Congress on Mine Design, Dept of Mining Engineering, Queen's University, Kingston, Ontario, Canada K7L 3N6. Tel:613 545 6553. Fax:613 545 6597.

AUG 24-26, 1993

Sydney, Australia.

VIII AUSTRALIAN TUNNELLING CONFERENCE - "FINDING COMMON GROUND".

Plenary Session Themes: Recent advances in excavation technology; Innovation in materials handling; Management of poor ground conditions; Contractual sharing of risk; Future exploitation of the underground domain. **Non-plenary Topics:** Contract mining for production operations; Major UG mine installations; Training people for the industries;

Improved public image of UG facilities; Major UG civil projects; The role of R & D in UG construction; Major capital works; UG occupational health and safety; Electrical and mechanical fit-outs; Minimising environmental impact. **Abstracts:** Jun 30, 1992. **Papers:** Mar 31, 1993.

The VIII Australian Tunnelling Conference Secretariat, The Australian Institute of Mining and Metallurgy, PO Box 122, Parkville, Victoria 3052. Tel:(03) 347 3166. Fax:(03) 347 8525; or

Terry Lanz, Conference Convener, Tel:(02) 979 5144. Fax:(02) 979 5239.

SEP 6-10, 1993

Krakow, Poland.

4th INTERNATIONAL SYMPOSIUM ON THE RECLAMATION, TREATMENT AND UTILIZATION OF COAL MINING WASTES.

Topics: Physical, chemical and geotechnical properties of coal mining wastes and fly ash; Deposition of waste materials; Ecological consequences; Use in civil engineering and hydraulic structures; Use as secondary materials; Reclamation of semi-derelict and derelict land; Frost susceptibility; Reclamation of spoil heaps. **Papers:** Jan 1993 to: Dr A.K.M. Rainbow, Head of Minestone Services, British Coal Corporation, Bedewell Park Suite, Victoria Rd, Hebburn, Tyne and Wear NE31 2HQ England. Fax (091)4890726. **Registration:** Dr Ing. Piotr Michalski, c/o Prof. Dr Drystyna M. Skarzynska, Dept of Soil Mechanics and Earth Structures, University of Agriculture, 24 Aleja Micheiwicza, 30-059 Krakow, Poland. Fax:(12) 33 6245.

Sep 13-17, 1993

Newcastle upon Tyne, UK.

INTERNATIONAL CONFERENCE ON ENGINEERED FILLS

Topics: Construction on, in and with engineered fills; Stabilisation and improvement of existing fills; Mechanical and physical properties of fills.

Dr B.G.Clarke, Department of Civil Engineering. The University, Newcastle upon Tyne, UK. Fax:(91) 222 6613. Tel:(91) 222 6419.

SEP 20-24, 1993

Athens, Greece.

INTERNATIONAL SYMPOSIUM ON HARD SOILS-SOFT ROCKS.

Topics: Geological feature; Mechanical properties and behaviour; Foundations, excavations and retaining structures; Slope stability and protection; Fills and embankments; Tunnelling and underground openings. **Language:** English and French. **Papers:** By Nov 1992.

Dr N. Kalteziotis, HS-SR Symposium, PO Box 20034 GR, 118 10 Athens, Greece. Tel:30 1 347 5830. Fax:30 1 346 7455.

OCT 19-21, 1993

Toulon, France.

INTERNATIONAL CONFERENCE ON UNDERGROUND TRANSPORT INFRASTRUCTURES.

Topics: Include site investigation for civil engineering projects. **Languages:** English and French.

Journees D'Etudes Aftes, c/o EDF Bureau 4/69, 22-30 avenue de Wagram, F-75008 Paris, France. Tel:33 1 47 6484. Fax:31 1 47 64 7588.

NOV 9-12, 1993

Tehran, Iran.

2nd INTERNATIONAL SEMINAR ON SOIL MECHANICS AND FOUNDATION ENGINEERING OF IRAN.

Themes: Problematic soils -swelling soils -collapsible soils -residual soils -dispersive soils -soils containing gypsum; Geotechnical design and construction -retaining structures -deep and shallow foundations -underground structures -soil improvement; In situ testing and measurements -penetration tests -stress-strain measurements -loading tests -soil behaviour monitoring. **Language:** Persian and English.

Organising Committee of 2nd International Seminar on Soil Mechanics and Foundation Engineering of Iran, Plan and Budget Organization (Technical Research and Standards Bureau), No 7 2nd Alley, Pakistan St, Dr Beshty Ave, Tehran (15316), Iran. Tel: 0098 021 624630/629368. Tlx:212642.

JAN 3, 1994

New Delhi, India.

INTERNATIONAL SYMPOSIUM ON UNDERGROUND CONSTRUCTION IN SOFT GROUND.

Topics: Earth and water pressure on braced walls and tunnel linings; Ground movements associated with underground construction. **Abstracts:** JUN 30, 1992. **Language:** English.

Prof. Keiichi Fujita, Dept of Civil Engineering, Science University of Tokyo, 2641 Yamazaki, Noda, Chiba 278, Japan. Tel:81 474 24 1501. Fax:81 471 239766.

JAN 5-10, 1994

New Delhi, India.

XIII INTERNATIONAL CONFERENCE ON SOIL MECHANICS AND FOUNDATION ENGINEERING.

Topics for Plenary Sessions: Soil properties; Foundations; Design and performance of retaining and buried structures; Embankment dams and dam foundations; Natural hazard mitigation. **Topics for Parallel Sessions:** Marine geotechnology; Computer application in geotechnical engineering; Construction instrumentation and real time management; Environmental geotechnology; Ground improvement; Foundations of old structures and monuments; Geotechnical engineering education; Professional practices; Arid climate soils; Liquefaction; Geophysical methods; Roads and tracks. Enquiries re papers from Australia to AGS Secretariat, Canberra.

Prof.Shashi K. Gulhati, Professor of Civil Engineering, Indian Institute of Technology, Organising Secretary General 13th ICSMFE, Post Bag No -28, Hauz Khas, New Delhi, 110016, India. Tel:91 11 6852540 or 653798. Fax:91 11 6852541.

JAN 27-28, 1994

Reno, Nevada, USA.

SYMPOSIUM ON DYNAMIC GEOTECHNICAL TESTING.

Topics: Field and laboratory test methods; Centrifuge testing.

ASTM, 1916 Race St, Philadelphia, PA 19103-1187, USA.

JUN 16-18, 1994

Texas A & M University, USA.

ASCE SPECIALTY CONFERENCE, SETTLEMENT 94.

Topics: Vertical and horizontal deformations for foundations and embankments.

Settlement 94, Geotechnical Engineering, Texas A & M University, College Station, Texas 77843-3136, USA. Tel:409 845 3735. Fax:409 845 6156.

SEP 5-9, 1994

Singapore.

5th INTERNATIONAL CONFERENCE ON GEOTEXTILES, GEO-MEMBRANES AND RELATED PRODUCTS.

Mr R S Douglas, Secretariat, 510 Thompson Rd No 0022-03 SLF Building, Singapore 1129, Tel: 3535511. Fax: (65)3532424

SEP 12-14, 1994

Sapporo, Japan.

INTERNATIONAL SYMPOSIUM ON PRE-FAILURE DEFORMATION OF GEOMATERIALS - MEASUREMENT AND APPLICATION (IS-Hokkaido).

Topics: Measurement and modelling of shear deformation properties of geomaterials (including those under dynamic and static loading conditions, but excluding purely theoretical work); Case study associated with shear deformation of ground and geostructures. **Abstracts:** Jul 31, 1993. **Language:** English.

Secretariat of IS-Hokkaido, Prof. Toshiyuki Mitachi, Department of Civil Engineering, Faculty of Engineering, Hokkiado University, North 13 West 8, Sapporo 060 Japan. Tel:011 716 211 ext 6192. Fax:011 726 2296.

SEP 21-23, 1994

Mamaia, Romania

Xth DANUBE-EUROPEAN CONFERENCE ON SOIL MECHANICS AND FOUNDATION ENGINEERING FOR INFRASTRUCTURE.

Theme: Soil mechanics and foundation engineering for infrastructure.

Prof. I. Manoliu, C.P. 38-71, RO-72302I, Bucharest, Romania.

MAY 28-JUN 1, 1995

Copenhagen, Denmark.

11th EUROPEAN CONFERENCE ON SOIL MECHANICS AND FOUNDATION ENGINEERING.

Theme: The interplay between geotechnical engineering and engineering geology.

Dr Jorgen Steenfelt, c/o ICS International Conference Services, Strandvejen 171, DH-2900 Hellerup, Denmark. Tel: 45 31 61 2195. Fax:45 31 2068.

SEP 25-29, 1995

Nakase, Japan.

8th INTERNATIONAL CONGRESS ON ROCK MECHANICS

Themes: Geology, site exploration and testing; Physical properties and modelling of rock; Near surface excavations, stability of slopes and foundations; Excavation and stability of underground openings; Heat, water flow and chemical transport in rock masses; Information systems and artificial intelligence in rock mechanics. **Preliminary Registration:** NOV 30, 1992.

Secretariat for 8th International Congress on Rock Mechanics, c/o Conference and Event Department, Simul International Inc, Kowa Bldg No 9, 1-8-10, Akasaka, Minato-ku, Tokyo 107, Japan.

JUN 17-21, 1996

Trondheim, Norway.

7th INTERNATIONAL SYMPOSIUM ON LANDSLIDES

Norwegian Geotechnical Society, PO Box 40, Taasen, N-0801, Oslo 8, Norway.