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Technical session 3b: Remediation

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1 INTRODUCTION

To provide a background to the papers selected for this session on contaminated land remediation it is appropriate briefly to consider the reasons for remediation and the constraints that may be imposed on remediation projects. The clean-up of contaminated land may be driven by local legislation/regulatory requirements or by voluntary action by the owner or occupier of the land. The legislation regarding the clean-up of contaminated land can vary significantly between different countries, however, there is likely to be some consideration of the following in all legislatures:

- the source-pathway-receptor model;
- that site remedial targets should be determined by risk assessment and not just the presence of contaminants;
- the polluter pays principle.

There can be little doubt that the source-pathway-receptor model provides a valuable framework for the analysis of environmental problems. However, its coupling with risk assessment merits some discussion. For example, typically in the context of contaminated land risk, is considered as:

Risk = Σ Probability of occurrence x Consequences

The summation must be carried out over each of the environmental media: air, water and land, consider the sub-compartments of these media such as human and ecological health; surface and groundwater as well as considering the generation of waste.

The aim of risk management then will be to reduce the overall risk to a level acceptable to society or other tests such as ALARP – as low as reasonably practicable.

As an example of risk management decisions, for municipal, industrial and nuclear waste repositories the probability of pollution is unity – it is certain that the repository will be a source of contaminants and although this may reduce over time, source reduction is not a practicable 'current' management procedure. Receptor management (prohibiting access to an area) will be impracticable as it would need to bind future generations beyond a time frame of about two generations (60 years) – longer than can be satisfactorily achieved in most legal systems. Pathway control thus becomes the only viable risk management procedure. This trivial example shows that risk assessment, properly used, is not merely a numbers game but an overarching framework development tool.

As an aside we may also ask how often are contaminated land risk assessors properly trained in risk? Should all risk assessors be required to follow a course in accident investigation? This can bring a proper 'reality' to risk assessment.

1.1 *Stakeholder understanding*

The requirement to reduce risk to a level acceptable to society requires that society must be able to understand the risk. For many situations the test of acceptability will be 'delegated' to regulatory bodies by legislation developed, it is to be hoped, by a democratic government. The tenet that proper pollution management requires democracy can be developed elsewhere but there is much evidence to support it and few convincing examples that it is not valid. Stakeholder understanding of pollution risk may be helped and promoted by environmental action groups. These are an essential component of environmental management – it must be possible for all sides to be heard and for the individual/stakeholder to determine for herself/himself what she/he recognises as fact and what as fantasy – remember environmental management requires consideration of future outcomes there cannot be certainty.

1.2 *The polluter pays principle*

The polluter pays principle is a feature of many national and international regulatory frameworks. It is certainly valid for new pollution but does it work with respect to legacies of industrial pollution. Is it still a source of delay and inaction. Is it no more than retribution for the actions of our grandparents?

1.3 *Sustainability*

In addition to the above considerations, it is becoming fashionable and perhaps also important to question the sustainability of individual contaminated land clean-up procedures. This requires consideration of social issues as well as the technical/environmental and economic. This is a challenge because currently there is no agreed assessment procedure and indeed it is doubtful if there ever will be a single overarching procedure as the social dimension properly requires consideration of ethics – an area constantly challenged by new technical developments. If sustainability remains on the agenda and is not overtaken by some new concept, which exposes flaws in our current thinking, then we must expect our ability to deliver sustainable projects to improve with time. It follows that what is sustainable in one country/society/level of development may not be sustainable in another country /society/level of development. Furthermore, we must seriously consider whether our present interpretation of sustainability or sustainability itself will remain relevant to future generations. We have after all moved on from concepts separate regulation of individual environmental media: air, water and land. We have recognised the need for a holistic approach to the environment with the introduction of national bodies such as environment agencies and international bodies for seas etc. We then took on sustainability. What next in a changing world?

1.4 *Technological development*

We should also note that although the changing world is a dominant theme in many technical-environmental discourses but it is not always recognised that it is not changing homogeneously. For many peoples, there is very rapid change in the way business is delivered and the way leisure time is used. However, for the major sources of pollution such as transport, extraction of raw materials, production of steel, cement etc. and domestic heating change is occurring over a much longer timescale. The half-life of a major materials production facility is much longer than that of a generation of portable computers – equipment that may be isolated and incapable of upgrading within 3 years despite the fact that it is still operational and performs it is original function. We must be cautious in suggesting that technical advances will lead to significant reductions in pollution. However, it also follows that we must take every opportunity to maximise the reduction that is achieved by new technologies since the technologies that are the largest contributors to worldwide pollution may change the most slowly.

It is also very important to keep a perspective on the significance of the geotechnical engineer's role in pollution management. We must not fall into the trap that says because there is measurable contamination it must be cleaned-up. We live in a world of finite resources. Money spent on the removal of low risks denies funds to higher risks and thus has an overall negative impact on health, safety, the environment and sustainability.

The above commentary is now possible because of the cumulative experience of many disciplines including geotechnical and geoenvironmental engineering built up over the last quarter of a century and more. Without this combined input we would lack the framework essential for the management of contaminated land – differentiating what needs to be done from what can safely be ignored; understanding how long remedial measures must and can last; developing an idea of what is an acceptable social and economic price to pay. From this background a consideration of the papers submitted to the session is now possible.

2 THE PAPERS SELECTED FOR THE SESSION

The papers selected for the session cover a wide range of topics demonstrating the breadth of the discipline of remediation and perhaps also the need to find an appropriate session within which to discuss the some of the less session-specific papers.

In total there were twenty eight papers selected for the session. These can be divided into five broad classes as follows:

ICSMGE Conference	16th	15th
Full-scale projects and case histories	4	1
Field investigation techniques	2	0
Laboratory investigations	11	5
Modelling including numerical modelling	4	5
Environmental protection, risk and sustainability	7	0

At the 15th ICSMGE Conference, Istanbul, 2001 there was no exactly equivalent session to this present session on remediation. The closest match was Session 5.1 Managing contaminated sites for which eleven papers were published and these can be approximately classified as in the table above. The conference also included a substantial and important paper by Professor Kamon entitled 'Environmental issues of geotechnical engineering'.

Thus for this 2005 conference, as for the 2001 conference and many previous conferences, the largest class of papers relates to laboratory investigations. There continues to be surprisingly few papers describing the performance of actual contaminated land remedial procedures.

2.1 *The scarcity of field data*

It is unfortunate that there is such limited presentation of field results and it is appropriate to make a plea to site owners, consultants and remedial contractors to ensure that information on the full-scale performance of remedial procedures is made available to the geotechnical community so that a proper audit trail can be developed from desk study to laboratory testing, design and then performance. Without data on field performance of remedial techniques – and especially long-term performance the discipline of contaminated land management risks being stigmatised as one with failures to hide whereas the proper message is that it is a discipline that has achieved stunning successes in the advancement of both theory and practice in an unbelievably short time.

3 FULL-SCALE PROJECTS AND CASE HISTORIES

Sadly there are only four papers on full-scale projects and case histories. However, they present some challenging projects. Two of the four relate to the management/remediation of contaminated sites. One relates to the management of waste and the fourth paper is on site dewatering.

3.1 *Contaminated land management and remediation*

The paper by Mukunoki, Rowe and Hurst discusses the performance of a geosynthetic barrier (GCL) used as a temporary measure to contain hydrocarbon spills at a site in the Artic. The paper presents a number of interesting results. The permeability to Jet fuel A-1 (also known as artic diesel) of a previously water permeated GCL was found to be surprisingly low. Furthermore, a GCL sample recovered after 3 years service on-site had a lower hydraulic conductivity to de-aired water than laboratory prepared samples. Freeze-thaw cycles did not have a negative impact on hydraulic conductivity with respect to de-aired water but they did increase the hydraulic conductivity with respect to Jet Fuel A-1. However, the hydraulic conductivity was still very low and the authors conclude that 'the GCL can be expected to perform well as a hydraulic barrier in the medium term with respect to the effects of both freeze-thaw and permeation with Jet A-1'. Samples were permeated with up to 12 pore volumes without significant increase in permeability – though at the time of preparation of the paper, tests appear to have been on-going with a trend of slightly increasing permeability with permeated volume.

The results are interesting showing that permeability of a GCL can remain low for significant permeated volumes of an LNAPL. Important features are that the GCL was pre-hydrated (as would be expected performance was not as good with partially saturated samples). Presumably by the nature of the test procedure – permeation with Jet A-1 after water, the Jet fuel was saturated with respect to water (hydrocarbons can dissolve some water and if not pre-wet, can draw water from a permeability test sample so causing a significant increase in permeability). The testing shows the very long test times necessary to achieve equilibrium between sample and permeating liquid. However, even if laboratory tests cannot be taken to equilibrium the data can be used to provide an indication of the time for which a site material will remain of low permeability – by scaling by volume permeated.

The paper by Ellefsen et al relates to the remediation of contaminated soil at Fornebu Airport, Norway and the stabilisation and re-use of PAH-contaminated soil from this former main airport which was redeveloped for residential and commercial use with large green areas and nature reserves.

The main clean-up started in 2000 and was completed in 2003. After treatment, the formerly contaminated soil was used for landscaping - reuse of the treated soil was one of the main environmental objectives for the development of the Fornebu area. This required management of the surface asphalt and the sub-base contaminated with tars (PAHs) of the oldest runways. The area involved was about 200,000 m^2 and the contamination was very unevenly distributed. In the most contaminated areas PAHs from the sub-base had penetrated 2-4 cm into the overlying asphalt.

20,000 tonnes of PAH-contaminated soil were stabilised with 3% bitumen in a cold mix stabilisation plant. The product was then used as a foundation for a new road. This obviated the need for transport and disposal of PAH-contaminated material to a hazardous waste facility at more than triple the cost. In addition to the stabilised material, 80,000 tons of PAH-contaminated soil were re-used in road foundations without stabilisation. Another 60,000 m^3 was later used for road construction and approximately 80,000 m^3 was used in construction of new terrain, without stabilisation. Of more than 200,000 m^3 of PAH contaminated, no more than 15,000 m^3 had to be disposed as hazardous waste. A re-use ratio of over 96% was achieved, far higher than the target figure of 75%. It should be noted that the paper makes it clear that the materials were subjected to leaching tests to confirm suitability before re-use.

The paper presents three very important findings of wide application:

- PAHs can be stabilised to prevent leaching using the similar material, bitumen;
- soil treatment and disposal to landfill can be vastly reduced if the remediation is designed as part of the works and not merely sub-contracted to a remediation contractor after the construction works have been designed;
- the remediation process should recognise the opportunities presented by the development and not just the constraints induced by the chemical and physical properties of the contaminants.

A point that is not addressed in the paper is the reaction of the occupants/purchasers of the new houses and commercial buildings to the contamination incorporated in the works. Were they made aware of it and did they welcome it as an appropriate use of material and avoidance of landfill or was it/will it become an issue of concern? Did the development pass the test of sustainability for the users as well as the engineers?

3.2 *Management of arsenic contaminated drinking water*

Hussainuzzaman and Yokota estimate that about 40 million people in Bangladesh are currently exposed to the risk of arsenic poisoning from drinking water. The presence of arsenic in drinking water poses two substantial problems – removal of the arsenic from the water to achieve safe drinking water levels and the safe management of the arsenic sludge produced by this water treatment.

For the arsenic removal a gravel-sand filter has been developed. Water from tube wells is pumped to the filter where the iron naturally present in the water (as Fe^{2+}) at concentrations of several mg/l is oxidised to Fe^{3+} and the arsenic (as As^{3+}) is oxidised to As^{5+}. The arsenic is adsorbed onto the now insoluble iron and precipitated as an iron-arsenic floc which is removed in the gravel-sand filter. The authors also carried out tests on disposal of the arsenic sludge including simulation of direct disposal of untreated material and solidification with Portland cement. Increased levels of cement addition (in the range 2 and 10%) were shown to produce increased retention of arsenic in the cemented material. The authors state that this is because of calcium arsenate formation but is this permanent? Could it be reversed and if so under what conditions? This is an important project, an arsenic removal and management system suitable for communities with minimal resources.

3.3 *Site dewatering*

Vermeulen and Day report on a dewatering project for Southern Africa's first Industrial Development Zone, at the Port of Ngqura. This project was effectively enabling works for part of a regeneration project rather than a remediation project. This demonstrates the breadth of work that now comes within the remit of environmental geotechnics. The work was to enable construction, in the dry, of a total of over 2 km of quay walls of average depth 20 m below sea level. The project involved 1.2 km of 20 m deep cement-bentonite cut-off walls with 43 perimeter deep wells and 28 internal wells. This is an important paper analysing an element of construction that is too often not fully discussed in papers – major dewatering works.

4 FIELD INVESTIGATION TECHNIQUES

There are two papers on field investigation techniques. These are on in-situ investigation of barrier performance and in-situ sniffing of sub-surface contaminants.

4.1 *Barrier permeability*

Soga et al present a procedure for the in-situ assessment of the performance of cut-off wall contaminant containment systems and in particular the quantification of engineering properties such as hydraulic conductivity. In-situ testing is preferable to laboratory testing as it enables testing of a substantial volume of material in as undisturbed a state as possible. A series of in-situ permeability tests were conducted in a relatively shallow eight year old cement-bentonite wall using a piezocone, a straddle packer system and a self-boring pressuremeter. The results suggest that not all of these methods are always suitable. The data also show that the measured permeability of the wall is often greater than that obtained from tests on small scale laboratory samples – this is probably due to heterogeneity of the wall at the field scale.

Soga et al conclude that the permeability values evaluated from the excess pore pressure dissipation during the piezocone tests were unrealistically high because of either fracturing or axial leakage. Their results suggest that standard CPT testing may only be applicable to walls at a very early age (i.e. just after construction), while older walls will require methods that do not cause high shear strains around the test device.

The permeability values obtained from the self-boring permeameter (SBP) were in general lower than the values obtained with the packer system – the drilling process appears to have had some effect on the permeability. However, the permeabilities obtained with the SBP and the packer tests were generally above those required by typical cut-off wall specifications. This was not unexpected as the bulk of published laboratory data on permeability testing relates to tests under confining pressures much higher than those which exist within most cut-off walls.

When testing cavities of increasing size, the authors found an apparent scale effect. This is likely to be the result of localised heterogeneity occurring in the form of fissures or inclusions. This finding is of significance for those who advocate inward permeation to counter outward diffusion from contaminated sites. Chemical diffusion from the contaminated side to uncontaminated side of a barrier may be relatively homogeneous but localised high advection implies that counteracting contaminant diffusion by advection may be largely ineffective as may be the use of retarding chemicals.

The authors note that for testing, in-situ mechanical properties may be just as important as permeability since it is the deformation characteristics which control the potential for cracking under the strains induced by in-situ testing (e.g. over-pressurisation of membranes). Current work is investigating this in order to help develop guidance on demonstrated procedures for in-situ assessment of slurry trench systems.

4.2 *Contaminant sniffing*

Kurup and Issac report a novel technology for sniffing subsurface contaminants. The paper describes the integration of a novel Electronic Nose (EN) with a Membrane Interface Probe (MIP) for rapidly screening gasoline contaminated sites. The MIP is an in-situ tool that samples volatile organic compounds from the subsurface and transports them through tubing to various detectors on the surface. The electronic nose is an automated odour recognition device that detects and identifies chemical vapours based on the principles of human olfaction.

In-situ demonstration tests were conducted in collaboration with the United States Environmental Protection Agency (EPA) to evaluate the EN-MIP technology in the field where it was successful in determining the exact depths of gasoline contamination and correctly determining concentration levels. On-site analysis of vapour samples performed by the EPA in their mobile laboratory provided confirmation of this. Predictions of the EN-MIP system were further validated by GC-MIP test results, and by conventional GC/MS laboratory analysis performed on soil and groundwater samples obtained from the test site. The results from the laboratory as well as the field testing have shown that the EN-MIP system is a reliable tool for rapid screening of gasoline contaminated sites. The authors note that additional field studies are needed to validate the technology in a variety of geological regimes and that research is currently in progress to increase the sensitivity and detection speed of the technology.

Whilst the authors have clearly demonstrated an elegant technique for the localisation of hydrocarbon contamination a question that remains is can the same ‘nose’ system be used for a wide range of contaminants? If it can, then the technology may provide a low cost and rugged alternative to on-site GC equipment.

5 LABORATORY INVESTIGATIONS

Laboratory investigations provide the largest group of papers offered for the session.

5.1 *Non aqueous phase liquids*

The paper by Kamon et al on the entrapment and dissolution behaviour of DNAPLs considers multiphase flow and contaminant transport and how the entrapment and dissolution behaviour of DNAPLs influences their spatial distribution in the subsurface and their remediation by pump-and-treat procedures. The applicability of a full hysteresis model of DNAPL infiltration characteristics was verified so that dynamic DNAPL entrapment behaviour could be properly quantified in a two-phase flow numerical simulation. Also, analytical results on DNAPL removal from the subsurface demonstrated that entrapment and rate-limited dissolution behaviour are key factors controlling remediation efficiency in the field.

In a second paper on DNAPLs, Liu et al discuss flow visualisation using transparent synthetic soils. The authors note that transparent materials including glass beads and quartz powder have been used in previous trials. However, glass and quartz surrogates are limited both by their poor transparency and their inability to represent the geotechnical properties of soils. This paper demonstrates the feasibility of producing transparent soils made of amorphous silica gels or powders and liquids with matching refractive indices that can be used for modelling flow in soils, whilst also representing the macroscopic geotechnical properties of a wide range of soils including sands and clays.

Movement of a contaminant through soil was modelled using a clear calcium bromide solution as the pore fluid and a red-dyed mineral oil to represent the contamination. 2-d flow tests with the oil through the transparent silica gel and fused silica were performed. The breakthrough curves for the oil through both materials were typical of the bell-shape reported for natural soils and image analysis clearly showed both the advection and dispersion processes. The authors state that the synthetic soil can be used to visualize and non-invasively measure pollutant transport in natural soils. Further work is in progress to refine the precision of the process. It offers a useful technique for those who want to visualise and quantify specific aspects of contaminant transport.

In a third paper on NAPLs, Nakajima et al investigated LNAPL lens formation using a centrifuge. Two-dimensional centrifuge model tests were carried out to simulate the movement of an LNAPL plume in the vadose zone and to investigate how LNAPL accumulates. The centrifuge model tests simulated LNAPL migration from a point source above the groundwater table and showed the formation of lens-shaped plumes that spread along the water table slope. Image analysis techniques including stacking and image arithmetic were found very useful in defining the plume boundaries in the experiments. Interestingly, the centrifuge tests showed slower movements and lower LNAPL propagation than numerical analyses – though overall the numerical analyses and centrifuge tests are reported as showing good agreement, especially the plume shape and propagation pattern. The authors conclude that this agreement lends credence to both their centrifugal modelling technique and their numerical procedure.

5.2 *Contaminant transport*

There are a number of papers on contaminant transport. Frippiat et al, undertook laboratory experiments to compare single-well and two-well tracer tests at laboratory scale to identify whether the dispersion parameters obtained from rapid and widely used tracer tests such as the single-well injection-withdrawal test can be used confidently when designing remediation techniques such as two-well injection-recovery systems. Their study suggests that although previous work tends to be pessimistic about single well techniques this type of test can yield apparent transport parameters applicable to two-well recirculation tests conducted on similar sampling areas and that single-well injection-withdrawal test should be preferred to radially converging tests when designing two-well injection-recovery systems.

In a second paper by the same team of authors (Conde et al) an elegant small-scale laboratory method to simultaneously determine longitudinal and transverse dispersivities is reported. A column system, classically used to determine longitudinal dispersivity, has been adapted by dividing the inlet and outlet regions into three independent concentric zones. Step variations in concentration are performed in the central inlet zone. The time evolution of concentrations in the three outlet zones is measured using electrical sensors. The slope of the resulting S-shaped curves is representative of the longitudinal dispersivity, while final concentration levels in each of the concentric zones are mainly affected by transverse dispersivity. The authors note that many kinds of two-dimensional tracer test schemes can be investigated, including non-uniform flow and that they found that the two-dimensional tracer tests in the soil columns seemed to be at least as effective as more classical one-dimensional tracer tests in terms of longitudinal dispersivity. The transverse dispersivity was found to be 1/30 of the longitudinal dispersivity at the test scale. More tests on longer soil columns are planned to verify the findings.

It is interesting to see that the divided inlet/outlet zone technique, previously used to investigate wall and other effects in hydraulic conductivity testing, has been successfully extended to investigate a more complex problem – dispersivity.

In addition to hydrodynamic dispersion, retardation of contaminants is a key issue in contaminant transport and several of the papers consider it. However, before considering the papers, it is important to recognise that retardation occurs as a result of binding to the soil and that:

- once all the available sorption sites on a soil have been saturated (at the input concentration of the contaminant) and any reactive material exhausted, diffusion and advection will proceed unretarded;
- the stored material can be re-released and at higher concentrations than it was originally present in the groundwater if the geochemical conditions change or if a rapidly moving (i.e. weakly sorbed contaminant) is displaced by a more strongly sorbed (and hence more slowly moving) contaminant – a process known as roll-up in chemical engineering;
- binding of contaminants to the soil is a competitive process. Single species tests in the laboratory may not predict the behaviour of chemical cocktails in the field, especially if one or more species are at significantly higher concentrations than the others;
- measured K_d values are concentration and time (time of soil/contaminant contact) dependent;
- a substantial literature is developing in this important area. It will be useful to develop and codify standard procedures.

Azevedo et al investigated the retarded diffusion parameters for zinc in a compacted gneiss residual soil to provide data on its potential as a barrier material in sanitary landfills. Initially the authors confirmed that the equipment they had developed functioned properly and that the effective diffusion coefficients they obtained from it were within the range of those reported in previous work. This is an important step and one that should not be omitted by those new to the testing regimes. They went on to show that test duration influenced the extraction results with longer zinc contact time with the soil resulting in a greater amount of strongly sorbed zinc.

Gabas et al investigated the sorption capacity of a compacted lateritic soil by sequential extraction. Diffusion tests were carried out on compacted soil specimens to investigate the mobility of the metals cadmium and lead in a tropical residual soil contaminated by acidic solutions at pH 3 and 5.5. After the diffusion step, a sequential extraction procedure was applied to the soil specimens. Both metals were significantly retained in the soil at pH 3 and pH 5.5. The authors concluded that:

- the oxide phase of the soil, mainly ilmenite, is responsible for the greater amount of retention of the two metals. They considered this type of retention to be stable due to the nature of the interaction between the surface of the oxides and the cations, i.e. specific adsorption;
- organic matter is important for the adsorption of lead – a finding which previously has been recognised but which deserves further research to elucidate mechanisms and the form of the bound material;
- with acid solutions dissolution of mineral grains can occur. This may seem obvious but is it always properly considered when estimating sorption and diffusion parameters?
- sequential extraction is the key to the evaluation of mobility and retention of metals in clay and may provide information that is not possible to obtain by diffusion tests alone.

It should be remembered that sorption on surface oxides can be compromised by organic-laden leachates (for example, from sanitary landfills) as the local redox potential may be affected by such contamination and thus the oxidation state of surface species changed.

5.3 *Freezing and drying*

Ito et al report the results of an interesting procedure to increase the permeability of soils prior to in-situ soil flushing (removal of contaminants by extracting contaminated water from the soil). The process involves freezing the soil and whilst it is relatively energy intensive and may take considerable time, it may be a technique that can be neatly exploited in countries where there is a harsh winter. The increase in permeability identified by the authors was significant – an increase in the rate of contaminant removal by a factor 7 to 10.

Ávila et al also discuss cracking but this time the damaging effects induced by drying and the problems that have occurred in a rural area close to Bogotá (Colombia). The research focused on understanding the hydro-mechanical processes involved and aimed to identify the conditions under which cracks form and the patterns of crack propagation. From the tests, it was possible to obtain the desiccation rate, the conditions (moisture content) for crack initiation, the effect of boundary conditions (smooth or rough base, size and shape of the mould), and the effect of re-hydration. Moisture content at crack initiation was found not to be a material property, but to depend on the initial moisture content, desiccation rate and especially on the restriction to free contraction imposed by the moulds. This is a useful study in an under-researched area – an area of considerable importance for many projects including landfill caps.

Santos and Cuéllar investigated a similar problem – that created by volumetrically highly unstable marls and clays when subject to drought conditions. They also considered remedial measures including the use of geomembranes and vegetation.

5.4 *Electrokinetic remediation*

Electrokinetic remediation is a well-researched area though the number of commercial projects completed may yet be small. There are questions about its sustainability as it is energy intensive. However, technical issues such as this should not be considered alone in sustainability assessments. The key issue is the benefits that a niche technology can bring to the overall sustainability of a project. If issues such as energy use are to be investigated an appropriate procedure is life cycle assessment. This is now a well codified discipline and if rigorously applied the resulting data can be used as a basis for cross-comparison of clean-up techniques.

Reddy and Maturi have studied an important problem that occurs on ‘real’ sites – mixed contaminants. Laboratory-scale electrokinetic experiments were conducted using a kaolin soil spiked with both a PAH (phenanthrene) and a heavy metal (nickel) to simulate typical field contamination. Different types of flushing solution were evaluated in a series of batch experiments and the most effective solutions were selected for the electrokinetic experiments. Based on the results, it was concluded that solubilisation of the contaminants as well as sustained electro-osmotic flow are the critical factors that contribute to the removal of both heavy metals and PAHs from low permeability soils.

5.5 *Heave of lime stabilised soils*

Sivapullaiah et al investigated the geotechnical behaviour of lime treated sulphatic soils. The study was under taken to understand the influence of sulphate content on two extreme types of fine-grained soils stabilised with lime: montmorillonitic black cotton soil and kaolinitic red earth. The authors concluded that in oedometer swelling tests the soils exhibited swelling due to adsorption of sulphate by the soil and that the black cotton soil also exhibits swelling due to flocculation of soil particles. They also stated that the compressibility of soils increases significantly in the presence of sulphate after one year of curing due to conversion of soil-lime pozzolanic reaction compounds into ettringite; that the strength of lime treated soils decreases after curing for long period in the presence of sulphate and that addition of barium chloride remediates the effect of sulphate.

The paper shows an equation (Equation 2) for the formation of thaumasite from ettringite. It should be noted that thaumasite can form directly, ettringite is not necessarily a precursor. Furthermore, the stated requirement for oxygen in the reaction is unusual and if supported would add a new dimension to the investigation of sulphate-induced heave. It would have been useful if the authors had provided references for this equation.

The finding of a two stage swelling mechanism for the black cotton soil which is not seen for the kaolinite is very interesting. Are the authors sure that the first stage is due to flocculation? It also should be noted that the swells they observed with the sulphate are modest compared with those that can occur in the field. It would seem that ettringite/thaumasite formation has had rather little effect in their experiments – indeed for the black cotton soil the swelling of the untreated soil was greater than for all but two of the sulphate treated soils. This apparently anomalous behaviour is a regular though explicable feature of laboratory investigation of sulphate heave.

The authors note that barium chloride can be used to 'remediate' the effect of sulphate. For a soluble barium salt to be effective, it must be added before the lime so as to precipitate the soil sulphate as low solubility barium sulphate before any sulphate induced heave has occurred. The effects of releasing barium into the environment also must be considered. If all the barium is precipitated as the sulphate then there may be limited immediate environmental consequences but what if some is washed out into watercourses prior to reaction or liberated from the precipitated barium sulphate by microbiological processes?

6 MODELLING INCLUDING NUMERICAL MODELLING

Two papers present numerical modelling of soil moisture profile during infiltration into vadose zone. Sugii developed a dynamic soil moisture model and compared the results with laboratory measurements – showing very reasonable agreement.

Zeballos et al also carried out a substantial laboratory /numerical modelling exercise – again providing good agreement between numerical modelling and laboratory testing in this important area.

Kaneda and Matsuo have carried out some very interesting numerical investigation of a coupled problem of land subsidence due to dewatering soft soils. Key findings were that:

- when dewatering exceeds a certain level, delayed consolidation with huge settlement can occur as a result of plastic softening of soils;
- after subsidence, the ground still may be vulnerable to settlement induced by further loading because of the disturbance of the soil skeleton;
- for a one-dimensional multi-layered system, delayed compression/consolidation of lower layers may occur even after the completion of the settlement of upper layers. This is due to the delay in propagating the increase of effective stress that occurs due to dewatering.

7 ENVIRONMENTAL PROTECTION, RISK AND SUSTAINABILITY

There were seven papers in this group. They cover a wide range of issues and provide interesting insights on risk from many different perspectives.

7.1 *Nuclear power plants*

Zhivoderov describes the problems that arose whilst arranging the protective geotechnical measures to mitigate the consequences of the accident at the Chernobyl nuclear power station. Although the accident occurred 18 years ago he finds that the regulatory documents still do not set out obligatory protective geotechnical measures for the power plant. Although his paper is particularly about nuclear power plants his findings are relevant to all forms of major accident and his conclusions should be studied by all involved in major accident prevention. These include:

- advances in the safety of nuclear power plants are possible only by a concerted collective approach, which takes into account all the known consequences of the disasters that have occurred to date;
- the management of contaminated underground and surface waters is of greatest importance and protective measures involve long-term problems of unprecedented complexity which can be solved only by uniting the efforts of international associations;
- in the event of a major accident at a nuclear power plant, the spread of the radioactive contamination although unpredictable is defined primarily by the direction and the strength of the prevailing winds.

7.2 *Minimising the environmental impact of dams*

Kudou et al present a new concept for rockfill dams with a focus on protecting the surrounding environment. They develop the theme that dams of substantial height but small area when used for pumped storage schemes can offer greater protection of the environment as a smaller area will be impacted. However, because of the regular change in water levels in these schemes it is necessary to know the unsaturated and saturated permeability of materials and the particular topic of this paper is the coarse materials that are used in filter zones where the flow regime may be turbulent rather than laminar as assumed in Darcy's equation. This can have consequences for the selection of appropriate hydraulic properties for coarse materials under rapid drawdown situations, and in the prediction of the residual pore water pressure distribution in the rockfill. They conclude that if the saturated-unsaturated hydraulic properties of coarse materials are properly considered, good rockfill dams which preserve the environment can be constructed but failure properly to consider non-Darcy behaviour can lead to dam failure.

It may be noted that turbulent flow in coarse materials is well recognised in chemical engineering reactor design and there is a substantial literature. Interdisciplinary initiatives on this topic may be rapidly rewarding.

7.3 *Re-use of materials in roads*

Lahtinen et al consider environmentally friendly systems to renovate secondary roads. They review innovations for the improvement and maintenance of secondary road networks and propose new road construction materials based on industrial by-products including fly ash and fibre-ash. New methods of mixing, application and construction control are also considered in relation to the quality and economic benefits of the renovation. They recognise that long-term observation will be needed to evaluate the performance of their pilot applications. However, their short-term experience already shows that their environmentally friendly and sustainable construction systems produce significant benefits for the society.

This is an area of considerable interest worldwide as roads use such large quantities of materials. Indeed in many countries a large proportion of all construction and demolition waste could be re-used in roads – provided that the performance of these materials over their new life cycle is understood and specifications are adapted to permit/promote their use.

7.4 *Risk perception*

Sarsby and Karri address risk perception and assessment at a brownfield site. There is an increasing need to redevelop such sites because of the rising demand for residential properties and the need to preserve greenfield sites. Indeed in the UK there is now a requirement that 60% of new homes are built on brownfield land. However, brownfield sites commonly contain substances and materials, from previous industrial activity, which can be hazardous to human health. The site they considered and the land adjacent to it had been previously used for an abattoir, a milk depot, a plant hire company and an engineering works. No evidence of widespread or pervasive contamination was found during the ground investigations at the site. However, some evidence of hydrocarbon contamination was found at an interface of clay and chalk strata. The hazard identification and hazard assessment stages of the risk assessment process indicated that the site did not pose a hazard to the proposed end users. However, as a result of the public perceptions of the site there was significant local interest in the future of the land. Local residents remembered the former industrial activity on the site and were concerned about its development. Therefore, it was decided that the general public should be involved in the decision-making processes and that communication should be maintained between all parties to minimise the public concern. However, the authors note that at the present time, the site still remains undeveloped. This paper presents a useful example of a technically 'safe' site, which carries a stigma within the local community – they know that some contamination remains and are hard to convince that it does not pose a risk. Has the 'perfect' in terms of sustainable stakeholder consultation become the enemy of the good?

7.5 *Vibration from construction works*

Svinkin considers environmental vibration problems during construction. His paper addresses an important problem, nuisance from vibration induced by construction works. Construction operations can result in environmental vibration problems for adjacent and more remote structures. Heavy vibrations can seriously disturb sensitive equipment, people and even cause structural damage. The author concludes that each construction site is unique and requires consideration of site specific conditions to mitigate vibration effects and that specifications for the control of construction vibrations should be prepared for major building projects. Also, self-evidently, a preconstruction condition survey should be conducted prior to construction activities. Whilst dynamic sources can be modified to some extent to comply with vibration limits for ground and structural vibrations, to reduce blasting vibration effects, it is imperative to manage the sequence of blasting and blast parameters. To reduce vibration effects from pile driving, it may be necessary to pre-drill holes and use the minimum hammer energy.

7.6 *In-situ/ex-situ treatment of drinking water*

Mulligan and Yong present a paper on evaluating the sustainability of methods for mitigation of arsenic contaminated aquifers. They start from the key premise that fresh water is a precious, non-renewable resource that is depleting rapidly in countries such as India, China, and even in the U.S. where rivers are drying up and water table levels are dropping.

To obtain safe drinking water in regions affected by arsenic contamination, two direct means are available: treatment of the water as it leaves the pumps (from the tube wells), and application of in-situ geochemical aquifer intervention procedures designed to control and mitigate arsenic pollution.

They conclude that in-situ geochemical procedures need to be structured to counter arsenic release from the source materials and that the in-situ geoenvironmental approach is substantially more sustainable than the ex-situ water treatment one as it does not produce wastes that need to be further treated; that is it removes the need for sludge treatment as described by Hussainuzzaman and Yokota. The suggestion that in-situ management is more sustainable than ex-situ treatment is simple to advance but it must be an area for debate. At what scale of operation (for example very small or very large) does an in-situ technique become less sustainable than an ex-situ technique which involves burial of arsenic sludge? In-situ techniques leave the arsenic in the ground at an unknown location where it may be released by subsequent changes to the geochemical environment – perhaps development/hard cover in the catchment area. Ex-situ treatment offers easier control and greater certainty. How do we assess the value this certainty against the need for more demanding waste management?

7.7 *Sustainability and harmony with the environment*

Jefferis, the author of this session report addresses the sub-title of the conference: "Geotechnology in harmony with the global environment" and questions whether this is a dream or deliverable and how harmony might be assessed. He argues that harmony with the environment cannot be achieved without sustainability and therefore sustainability must be considered as a first step. An attempt is then made to develop a procedure to assess sustainability using life cycle assessment as a model and taking into account human values.

It is shown that sustainability is not an abstract principle but a concept informed by measurable technical and economic factors though input on human values also is essential but less easily obtained. All these values will vary locally, nationally and internationally. A common position on sustainability therefore may not be desirable if indeed it were possible. However, this does not mean that sustainability can be assessed by any procedure developed at the whim of the assessor. Consideration of the standards for Life Cycle Assessment (LCA) shows that if transparency is to be achieved and the results used by the wider community, rigorous procedures must be developed. A number of challenges remain:

- Is sustainability an absolute test or a relative test? That is can we say development A is sustainable but development B is not or merely that A is more sustainable than B?
- Sustainability requires consideration of perspective including for whom is it to be sustainable, local-global, present day-future generations etc. For geotechnical engineering, what should be the perspective, the goal and scope?
- Can sustainability be assessed for a single construction element such as a pile or is it essential to consider a complete project such as major pan-national infrastructure project? LCA can provide useful information at every level but as regards sustainability, the whole is the sum of parts. Many different components may be used and they can be assembled in many different ways. Some of the assemblies may be more sustainable and others less so.

- Indicators of sustainability need to be developed. Many can be 'borrowed' from existing procedures but should geotechnical/civil industry specific indicators be developed?
- Can company-focused key performance indicators be re-worked to promote sustainable approaches?
- Will consideration of sustainability lead to better construction? Codification of sustainability analyses may promote pressure-state-response thinking, i.e. a mind-set which seeks to identify existing problems and solve them. This can be an enemy of blue-sky thinking. We must be careful that codification does not promote end-of-pipe solutions which manage rather than remove problems.
- How should the results be used and at what scale? Will sustainability become a legal test like human rights?

8 CONCLUSIONS AND QUESTIONS FOR DEBATE

From this fascinating though diverse array of papers what topics should form the basis for discussion at the conference session on remediation? The author of this review has found it difficult to draw general conclusions and therefore prefers to ask delegates to consider some of the wider problems that beset contaminated land remediation. It is important that an international conference is used to maximum advantage to exchange ideas and explore future needs and future developments. The following questions are therefore posed:

1. Today, contaminated land management often leaves much slightly contaminated material in the ground. Are we comfortable with current risk assessment procedures and that we have established appropriate clean-up targets especially for housing – but recognising that contamination from land is often a minor contributor to the 'pollution' intake to the body – polluted air may be much more significant. If we waste money removing low risks we deny it to the high risks.

2. Are containment, stabilisation and landfilling of contaminated soils valid clean-up procedures? They are accepted, indeed promoted in many countries but are there alternative views? Should we be focusing on thermodynamics of contaminant-containment interaction and not adding ever further refinement to the physical engineering of barriers? Can we realistically design long-term containment/stabilisation systems without reference to thermodynamics?

3. Is the main issue introduced by sustainability analyses managing stakeholder confidence in remedial performance?

4. Does the polluter pays principle promote or delay contaminated land clean-up?

5. Are NAPLs still a major issue? Do we understand their movement? Can we locate deep DNAPL zones? What are the main research needs?

6. What will be tomorrow's problem contaminants both as regards clean-up of historical contamination legacies and prevention of future contamination?

7. Are we confident about the durability of remedial measures? Can we find all the contamination on a site? Are we managing it all?

8. Site investigation techniques are rapidly developing. A range of in-situ/on site analytical/identification/sniffing procedures is available. Should we be moving from laboratory testing to on-site and in-situ testing? The rapid availability of data can substantially reduce remediation costs – reductions of the order of 20% to 70% are quite possible. Are we taking full advantage of on-site techniques?

9. Are laboratory measurements always the 'gold standard'. Do we understand/enquire enough about extraction procedures and the performance of laboratory analytical regimes? Are we aware that some laboratory protocols may extract and therefore quantify only part of the contamination present in a sample – recognising, of course, that controlled partial extraction is key to the assessment of certain properties such as bioavailability?

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