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Technical session 3a: Waste disposal and management

Séances techniques 3a: Traitement et gestion des déchets

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1 INTRODUCTION

This paper provides an overview of the papers in Technical Session 3a: Waste Disposal and Management. Thirty-three papers were received for this session with authors from 17 nations. Five papers were received from North America, 2 from South America, 16 from Europe, 8 from Asia, and 2 from Australia. One of the papers from Asia was co-authored by a person from Africa. Thus, 6 of the 7 continents are represented in this session (no papers were received from Antarctica, which is not surprising!).

The papers can be segregated into 8 topics: contaminant transport issues, mechanics of waste containment, engineering properties of wastes and contaminated soils, nuclear waste containment, unsaturated soil issues, assessment of barrier materials, cutoff walls, and "other" topics. The number of papers in each category and the nations contributing these papers are summarized in Table 1. Some of the papers could have fit into more than one category, but are listed in only one category in Table 1.

The following sections provide a summary of the papers in each area, with emphasis on some papers of particular importance.

Table 1. Summary of papers in each category.

Topic	No. Papers	Contributing Nations
Contaminant transport	7	Belgium, Brazil, Italy, Slovenia
Mechanics of waste containment	8	Australia, Bulgaria, Croatia, Germany, Japan, Spain, US
Wastes and contaminated soils	5	Australia, India, Japan, Singapore, UK
Nuclear waste containment	4	France, Japan, Sweden
Unsaturated soils	3	Germany, France, US
Barrier materials	2	Japan
Cutoff walls	2	Italy, Japan (with Kenyan author)
Other	2	US

Note: Papers in "Other" category include a field study on the thermal properties and gas characteristics of solid waste landfills and a laboratory study on filtration properties of geotubes.

2 CONTAMINANT TRANSPORT

2.1 *Chemico-Osmotic Effects on Transport*

Three of the seven papers on contaminant transport deal with the influence of chemico-osmotic effects. Malusis and Shackelford (2002) elucidated the importance of chemico-osmotic effects for barrier systems. They showed that the rate of diffusive transport of inorganic species in bentonite can be reduced by osmotic effects when the influent liquid is a dilute aqueous (< 50 mM) solution containing monovalent cations. However, the reduction in diffusive transport was appreciable (i.e., > 10%) only when the solutions are very dilute (< 10 mM).

Malusis and Shackelford (2002) quantified the reduction in diffusive transport by the chemico-osmotic efficiency coefficient, ω, which is zero when the osmotic effect is completely absent and 1 when the osmotic effect causes complete cessation of diffusive transport. The dependence of ω on concentration is shown in Fig. 1 for solutions containing only monovalent cations. The efficiency is > 0.6 for concentrations < 3 mM, and less than 0.15 for concentrations greater than 50 mM.

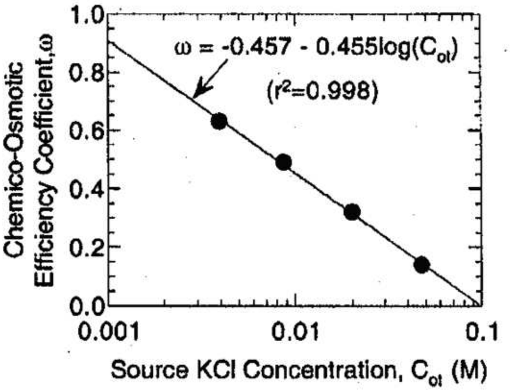

Fig. 1. Chemico-osmotic efficiency coefficient vs. concentrations for dilute KCl solutions (adapted from Malusis and Shackelford 2002).

Subsequent experiments by Shackelford and Lee (2003) with dilute (5 mM) solutions containing divalent cations showed that the osmotic effect can be short-lived (< 30 d) if cations in the influent liquid are divalent or polyvalent. They attributed the loss of the osmotic effect to compression of the adsorbed layer and collapse of the interlayer space in the montmorillonite particles in response to Ca-for-Na exchange on the clay surface.

The paper by Van Impe et al. in these proceedings presents results of a modeling study conducted to assess the error that can be incurred when osmotic effects are ignored when analyzing column tests. For ω < 0.2, which should be expected in most natural systems and waste containment systems, ignoring osmotic effects results in an error in the diffusion coefficient and retardation factor that is less than 20%. This magnitude of error is probably within the range of error associated with most laboratory tests (except specialized tests for research purposes) and certainly is within the envelope of variability expected in a full-scale system. However, van Impe et al. indicate that the error generally increases as the Peclet number increases. Thus, data from tests conducted at higher seepage rates will be prone to greater error when osmotic effects are ignored.

The other papers on osmotic barrier effects in these proceedings are authored by Dominijanni and Manassero and Mazzieri et al. Dominijanni and Manassero provide a theoretical explanation for the linear relationship between the osmotic efficiency and the chemico-osmotic diffusion coefficient that is consistent with the data reported by Malusis and Shackelford (2002) (Fig. 2). However, they did not compute ω directly with their method or compare theoretically computed ω with the experimentally obtained ω reported by Malusis and Shackelford (2002). Mazzieri et al. show that a bentonite treated with propylene carbonate exhibits similar osmotic behavior as conventional bentonite, and illustrate the same loss of osmotic effects as Shackelford and Lee (2003) in tests conducted with a 5 mM $CaCl_2$ solution.

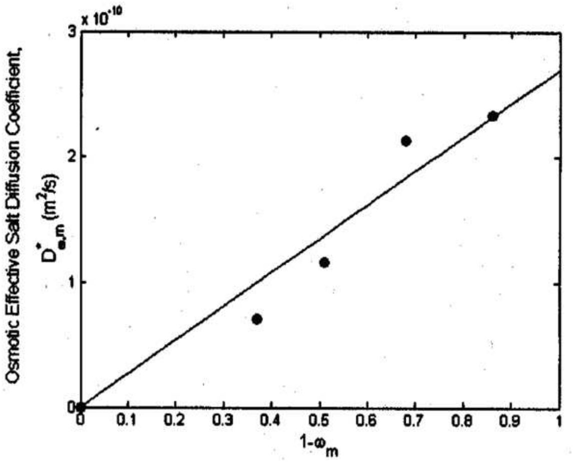

Fig. 2. Linear relationship between the chemico-osmotic diffusion coefficient ($D_{\omega,m}$) and the osmotic efficiency (ω) reported by Dominijanni and Manassero (these proceedings) with data from Malusis and Shackelford (2002).

One issue that is not dealt with in any of the papers, but is of great practical importance, is defining the natural and engineered systems in which osmotic effects are likely to be important. For example, divalent cations are ubiquitous in most natural and engineered systems, and the ionic strength of leachates in most waste containment systems exceeds 50 mM (Kolstad et al. 2004), both of which would preclude appreciable osmotic effects. Moreover, most barrier systems are constructed with clays other than bentonite (Benson and Trast 1995) (geosynthetic clay liners and soil-bentonite cutoff walls excluded), and the importance of osmotic effects in clays other than bentonite has not been demonstrated.

2.2 *Other Transport Issues*

The remaining four papers on contaminant transport in these proceedings each deal with different issues. Carrara et al. describe large-scale column experiments conducted to determine the extent to which spills of phthalate acid ester (PAE) will infiltrate in surficial soils during a spill. They show that a dose of PAE migrated only 660 mm into the soil profile in their experiment, which was conducted with a sandy clay. However, the tests were conducted with only one soil and under one condition. Thus, the depth and rate of migration in different soils and other hydrologic scenarios is not clear.

Tsugawa et al. describe diffusion tests conducted to study the release of metals from a residual clay under acidic conditions (pH 1 solution prepared with HNO_3 or HCl). In general, their findings are consistent with well known principles in soil chemistry. They found that Al was released at very high concentrations (probably due to dissolution of quartz or clay minerals at low pH) and Na, Mg, K, and Ca were released at modest concentrations. The concentration of Fe was unexpectedly low, given the abundance of Fe in the soil.

Rabozzi and Manassero describe an evaluation of phenol transport in clay liners. They show that the degradation of phenol during transport is described equally well with Monod and first-order kinetic expressions, and indicate that better predictions of transport can be obtained if the analysis accounts for the effects of degradation on the source concentration. The importance of considering a time-varying source concentration was also shown by Kim et al. (2001) in their experiments dealing with VOC transport in clay liners.

Petkovsek et al. describe a case study regarding the Ljubljana landfill in Slovenia. Both mechanical and environmental aspects are described in their case study. The environmental assessment showed that migration of metals from the landfill was strongly controlled by redox conditions. Their findings suggest that reactive transport modeling is needed to predict metals transport when assessing the environmental impacts of landfills.

3 MECHANICS OF WASTE CONTAINMENT

3.1 *Stability and Settlement*

Five of the eight papers on mechanics of waste containment deal with stability and/or settlement of wastes and containment facilities. Two of these papers are case histories, two are laboratory studies evaluating engineering properties, and one paper evaluates a method to predict settlement.

The case histories are described in the papers by Fernandez et al. and Sagaseta et al. Fernandez et al. describe a case history where leachate recirculation in a Columbian landfill led to a slide within the waste mass. Excessive pore pressures developed within the waste mass due to high leachate injection pressures and poor drainage within the waste, which led to a weakened waste mass and failure. They illustrate the importance of proper design and analysis of systems used for leachate and gas collection and leachate injection. They also show that conventional soil mechanics based on effective stress principles can be used to assess the stability of solid wastes, and point out that the low unit weight of many solid wastes can render waste slopes more vulnerable to instability than comparable earthen slopes. Sagaseta et al. describe the closure of a tailings dam in Spain, and the utility of using the CPT to quantify increases in strength that occur as the tailings consolidate.

Itoh et al. and Ivsic et al. describe laboratory studies related to the mechanics of waste containment systems. Itoh et al. studied the shear strength and compressibility of waste from a Tokyo landfill that contained incombustible wastes and waste incinerator ash. They found that the behavior of the wastes was consistent with the principles of soil mechanics using effective stresses, and indicate that Tokyo landfill wastes tend to be strong, but highly deformable, as has been shown by others for municipal solid waste (see Edincliler et al. 1996 for a review). They also show that creep of Tokyo wastes can be a significant, and recommend that the waste be stabilized by compaction or using cementitious binders if the land is to be reused for infrastructure.

Ivsic et al. describe the effect of immersion and saturation on the interface shear strength of clay-geomembrane interfaces. Under undrained conditions, they show that the interface shear strength is much lower when the clay is saturated than when it is unsaturated. The reduction in strength is most likely due to development of positive pore water pressures during shearing.

Abreu et al. describe a new model for predicting the immediate settlement of municipal solid waste that relies on a hyperbolic model of the stress-strain relationship for waste. Parameters of the model were related to the initial unit weight of the waste. Comparison of predictions made with the model and data from a field test showed that the immediate settlement was predicted within 20% of the settlement measured in the field test.

3.2 *Innovative Design Case Histories*

The other three papers related to the mechanics of waste containment are case histories related to innovative design issues. These papers are described in the following paragraphs.

Blumel et al. describe a case history where a roadway carrying heavy traffic was constructed over a landfill near Hanover, Germany. Support for the roadway was provided by a layer of geogrid-reinforced slag supported by vibro-concrete columns (Fig. 3). Gas and water drainage layers were also included to prevent water from entering the underlying wastes and to manage gas emissions from the landfill. The support system was very effective, with plate load tests indicating that the modulus of the reinforced slag layer was 50-55 MN/m^2 between the columns and 60-70 MN/m^2 above the columns. German road construction criteria require a minimum modulus of 45 MN/m^2.

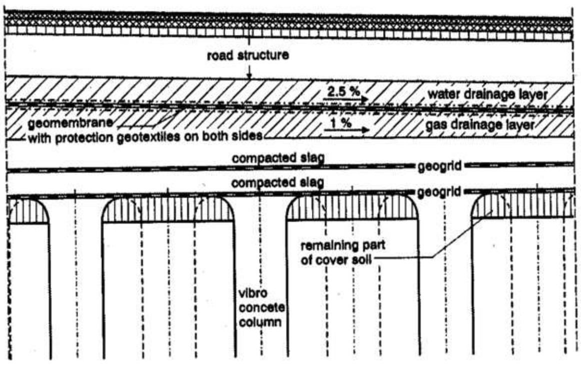

Fig. 3. Cross-section of reinforced roadway used to carry heavy traffic over a landfill near Hanover, Germany.

Aravind and Terzaghi describe innovative aspects of a landfill located in Southland, New Zealand where elevated pore water pressure beneath the landfill required special considerations. An underdrain was used beneath the liner to relieve pore water pressures and to serve as a leak detection system. The leachate storage tank was also mounted on piles to prevent uplift due to pore water pressure. Other important aspects of the design included the use of coarse river gravel for the leachate collection system to minimize clogging and a test pad program to address unique aspects of the clay component of the lining system, which was constructed with unusual on-site clays rich in chlorite and calcium montmorillonite.

Kaltchev et al. describe difficulties associated with evaluating the mechanical properties of an overburden dump material at a mine in Bulgaria that contained a varying amount of coarse particles. The dump material is also prone to reductions in particle size in response to weathering. The numerical model PLAXIS was used to invert mechanical properties of the dump material from settlement data.

4 WASTE MATERIALS AND CONTAMINATED SOILS

4.1 *High Water Content Materials*

Four of the five papers on the engineering properties of waste materials and contaminated soils deal with high water content materials (sewage sludges, sand mining slimes, and dredgings/tunneling residuals).

Sarsby evaluated the compressibility and undrained shear strength of sewage sludges in the UK. He indicates that the properties of sewage sludges are similar to organic soils. Sewage sludges can be treated as normally consolidated materials with virgin compression indices (Cc) ranging between 1.5 and 10, with higher Cc at lower effective stresses. He also indicates that the undrained shear strength of sewage sludge increases exponentially with unit weight and that the ability to strengthen sludges is tied directly to their ability to drain. Several additives were evaluated that might improve drainage of sludges, but none were found to be effective.

Chu et al. evaluated using lime and Portland cement to stabilize sewage sludge from Singapore. They found that lime and cement were not effective in improving the shear strength of sewage sludge. The unconfined compressive strength of the sludge remained below 30 kPa, even when 25% cement was added. The lack of improvement is most likely due to inhibition of cement reactions by organic matter in the sludge, as is commonly observed when chemically stabilizing organic soils (Hampton and Edil 1998).

Nakai et al. evaluated using a rotary chain mixer to dewater and aggregate sludge cakes. The end product consists of aggregates of drier fine-gained material that can be compacted like fine-grained soil.

Bouazza and Wang evaluated the hydraulic conductivity of slimes from sand mining pits in the vicinity of Melbourne, Australia with the intention of using the slimes as a barrier in waste containment systems. Their studies showed that hydraulic conductivities less than 3x10^{-8} cm/s can be achieved using slimes. However, the presence of heavy metals may prevent use of slimes for waste containment.

4.2 *TCE Contaminated Soil*

Srivastava describes how the engineering properties of a sandy clay contaminated with trichloroethylene (TCE) change as the soil is decontaminated with surfactants. The TCE concentration in the soil range between 0 and 4% by weight. The soil became more plastic as the TCE concentration was reduced, suggesting that decontamination may render soils more compressible and weaker than in their contaminated state.

5 NUCLEAR WASTE CONTAINMENT

Four papers in the proceedings deal with nuclear waste containment. Three of the papers deal with transport of heat and/or water in backfill materials. The other paper deals with grouting hard jointed rock.

Gatmiri and Robinet et al. both discuss modeling of heat and water flow in deformable backfill materials. Gatmiri used Code-Aster, whereas Robinet et al. used the CLEO code. Both codes employ the finite element method to solve coupled partial differential equations describing the flows of heat, liquid, and vapor along with volume change, and were used to make predictions for bentonite materials used to backfill waste canisters. The models show water flows due to thermal gradients tend to be much greater than flow due to vapor pressure gradients.

Robinet et al. compare predictions made with CLEO to temperature and humidity data from a field test. CLEO predicted the trends in temperature reliably, but the temperatures generally were under-predicted. The variation in humidity observed in the field was not captured in the model prediction.

Komine presents equations that can be used to predict the hydraulic conductivity of dense bentonite backfills where the dominant component of flow occurs in the interlayer of the montmorillonite particles. The equations are based on laminar flow between parallel plates and account for the composition of the exchange complex and the montmorillonite content of the bentonite. Reasonably good agreement was obtained between hydraulic conductivities predicted with the equations and hydraulic conductivities of bentonites measured in the laboratory (Fig. 4).

Eriksson et al. describe a methodology for efficient grouting of hard jointed rocks in Sweden in which a nuclear waste repository is planned. The methodology links hydrogeological testing with core hole information to determine an efficient grouting scheme where the volume of grout is minimized.

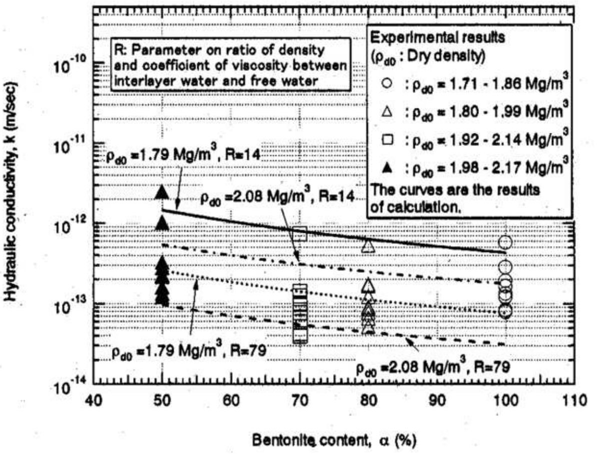

Fig. 4. Hydraulic conductivities of bentonite backfill predicted using Komine's equations and measured in the laboratory

6 UNSATURATED SOIL BEHAVIOR

Three papers in the proceedings deal with unsaturated soils and waste containment. These papers deal with hydraulic and mechanical issues.

McCartney et al. describe two large-scale (200-mm-diameter) column tests (Fig. 5) that were conducted to evaluate the capillary break effect caused by placing a coarse material beneath a layer of fine-grained soil. One column consisted of silt over sand, and the other was silt over a geocomposite drainage layer. Soil in the columns was wetted from above using a constant flow rate. Water contents within the columns were measured using time domain reflectometry as water penetrated the soil profiles.

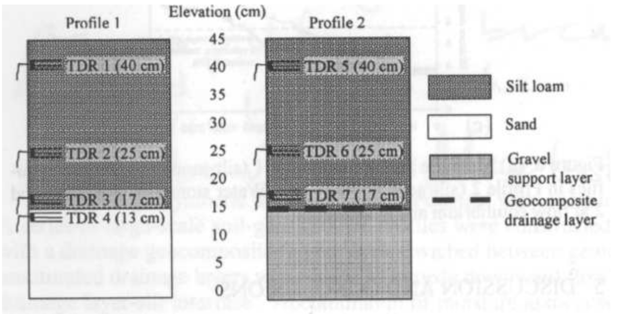

Fig. 5. Columns used by McCartney et al. to study the capillary barrier effect.

The capillary barrier effect occurred in both columns, as illustrated in Fig. 6 for the column with silt over sand (i.e., water contents gradually increase in the silt layer, while the water content in the sand remains essentially unchanged until the silt layer is nearly saturated; then breakthrough occurs). The tests also showed that the silt wetted to a higher water content prior to breakthrough when the geocomposite drainage layer was placed beneath the silt. This finding is consistent with theory described in Khire et al. (2000), which shows that the water content of the finer layer at breakthrough increases when the underlying layer is coarser (i.e., the drainage layer has larger pores than the sand layer).

Calculations made by the author using soil water characteristics curves reported in McCartney et al. and the theory in Khire et al. (2000) show that the theory and experimental data are in reasonable agreement. The computations showed that breakthrough should occur when the water content in the silt layer at the capillary break is 0.38 (sand layer) or 0.44 (geocomposite drainage layer). The experiments showed that the water content in the silt was 0.37 at breakthrough when sand was the underlying layer, and 0.40 when a geocomposite drain was the underlying layer.

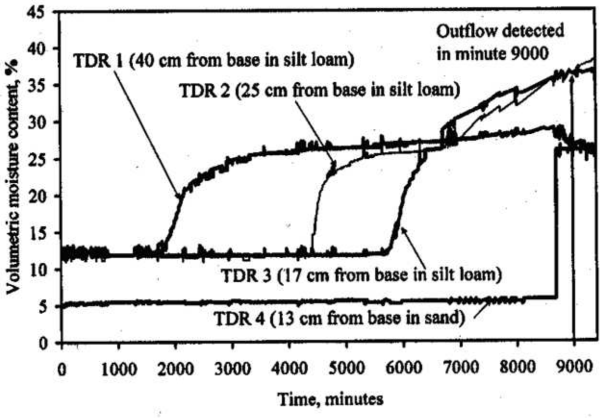

Fig. 6. Water contents in the silt and sand layers during infiltration. Note that water content in the sand layer remains essentially unchanged until the water content of the silt is approximately 0.37.

Taibi et al. report on instantaneous profile experiments used to determine the unsaturated hydraulic conductivity function of a compacted clay barrier soil. The measured hydraulic conductivities are compared with hydraulic conductivities predicted with the Fredlund-Xing model. Taibi et al. indicate that the measured and predicted unsaturated hydraulic conductivities are in good agreement. However, close inspection of their data indicates that the measured hydraulic conductivity is considerably higher than the predicted hydraulic conductivity for suctions exceeding 20 kPa. The under-prediction for clayey soils was previously described by Meerdink et al. (1994), Benson and Gribb (1997), and Chiu and Shackelford (1998), and is largely due to assumptions made regarding pore interaction terms in the unsaturated hydraulic conductivity model.

Zeh and Witt describe how the tensile strength of compacted clay varies with suction, which is an important factor affecting desiccation cracking of clay barriers. They describe a test method to measure the tensile strength of compacted clay and provide a model to describe the variation of tensile strength with suction. However, a theory coupling suction, tensile strength, and cracking of compacted clay barriers still needs to be developed.

7 BARRIER MATERIALS

Two papers in the proceedings deal with assessing earthen materials used for hydraulic barriers. One paper deals with chemical compatibility of bentonites in geosynthetic clay liners (GCLs). The other deals with sorption of Cd and Pb on a compacted clay.

Katsumi and Fukagawa conducted tests on GCLs containing granular or powdered bentonite. They show that the hydraulic conductivity of GCLs prepared with powdered bentonite is less sensitive to chemical interactions, and attribute this to smaller pores between the granules of powdered bentonite. Katsumi and Fukagawa also demonstrate that free swell is a good indicator of the hydraulic conductivity of bentonites in GCLs, as was previously suggested by Jo et al. (2001) and Kolstad et al. (2004). Data from compatibility and free swell tests they conducted with leachates agree with a hydraulic conductivity-swell relationship developed based on controlled tests conducted with salt solutions (Fig. 7). This suggests that free swell tests can be reliably used as a screening tool for evaluating the chemical compatibility of GCLs with leachates.

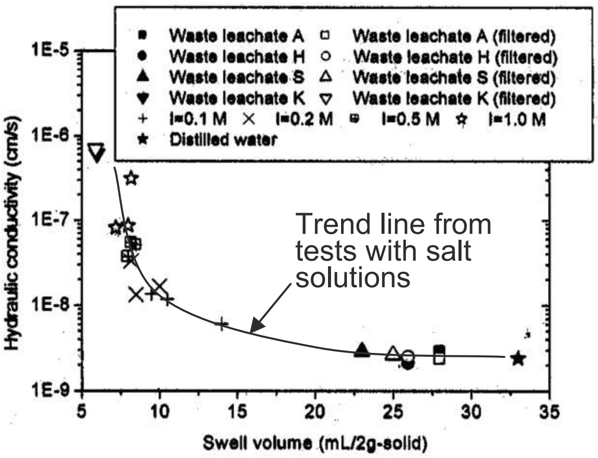

Fig. 7. Hydraulic conductivity-free swell curve along with data from tests conducted with leachates.

Du and Hayashi evaluated the transport properties of lead in Ariake clay, a potential liner material. Batch and column tests were used for testing. Partition coefficients, computed from isotherms constructed from the batch test data, decreased as the solid:solution ratio increased. Good agreement was obtained between partition coefficients from the batch tests and those computed from the column tests when the solid:solution ratio in the batch and column tests was similar. Diffusion coefficients obtained from the column tests were in general agreement with values reported in the literature.

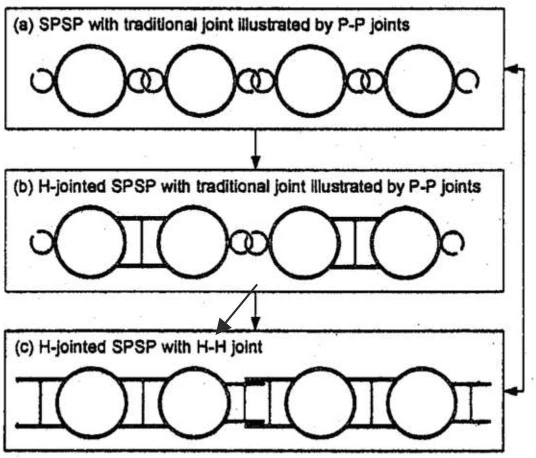

Fig. 8. Joints for SPPs evaluated by Inazumi et al.

8 CUTOFF WALLS

Two papers in the proceedings deal with groundwater cutoff walls. One paper focuses on the properties of a hybrid sheet pile, whereas the other describes a chemical compatibility assessment of a cement-bentonite backfill.

Inazumi et al. compare the mechanical and hydraulic characteristics of conventional steel pipe pile (SPP) walls with pipe joints to the characteristics of hybrid SPP walls employing a joint comprised of two H-piles (Fig. 8). They also evaluated a joint sealing paint that swells when the joint is in water. Tests in a geotechnical centrifuge showed that the hybrid wall is more rigid than conventional SPP walls, permitting more accurate driving and less chance for an open joint. Hydraulic conductivity tests showed that the hydraulic conductivity of the joints in the hybrid wall could be less than 10^{-8} cm/s when sealed with the swelling paint.

Fratalocchi et al. describe immersion and permeation tests conducted with an acidic solution to assess the compatibility of a cement-bentonite (C-B) cutoff wall material. The immersion tests suggest that the C-B is resistant to deterioration by the solution. The permeation tests showed that the hydraulic conductivity of the C-B decreased throughout the duration of the test. Although chemical equilibrium was not necessarily achieved in the permeation test, the data do suggest that the C-B will maintain low hydraulic conductivity for 150 y under field conditions.

9 OTHER

Two other papers in the proceedings that deal with waste management issues, but did not fall into the previously cited categories, are described in this section. One of these dealt with temperature and gas monitoring in a solid waste landfill and the other with filtration in geotubes used to contain contaminated sediments.

Hanson et al. describe temperature and gas data collected from a landfill located near Detroit, Michigan, USA. The landfill was instrumented with a collection of sensors to monitor the distribution of temperature as well as CO_2, O_2, and CH_4 contents in the gas phase. They found that temperature and gas concentrations vary seasonally near the boundaries of a landfill, but remain relatively constant or change monotonically in the interior. Temperatures on the order of 56 ^{o}C were obtained in older waste in the interior of the landfill after several years. The maximum temperature at the liner was 30 ^{o}C. The greatest changes in temperature occurred within the first year, during which the gas data showed that the landfill was transitioning from aerobic to anaerobic conditions.

Kutay and Aydilek report on gradient ratio tests conducted to assess filtration of sediments in geotubes. They evaluated filtration by a conventional woven geotextile and composites consisting of a non-woven geotextile and a woven geotextile. The non-woven geotextile was oriented upstream in all tests conducted on composites. The two-layer composites generally exhibited lower gradient ratios than single geotextiles, indicating that geotubes made with geotextile composites may be more effective in filtration.

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