Journal of Hazardous Materials, 14 (1987) 39—49
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

CONTAINMENT OF UNCONTROLLED HAZARDOUS WASTE SITES

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(Received April 30, 1986; accepted June 15, 1986)

Summary

Conventional as well as new approaches to contain hazardous waste sites are examined. Some recommendations on how to deal with the uncertainty in the engineering containment of these sites are made.

Introduction

Since the inception of CERCLA, we have applied a number of technologies to contain the movement of contaminants from uncontrolled hazardous waste sites. In some cases, we have applied technologies developed in other industries and in others we have developed and applied new approaches.

Most containment system concepts include design features that limit or prevent surface or ground water movement into the contaminated area or prevent contaminant migration from the site since water pathways are the principal mechanism for subsurface contaminant migration. There is a basic understanding of the uncertainty in these design concepts from our experience on a host of projects where these control technologies evolved. We have a tendency to except more from containment technologies than the state-of-the-art allows. Many of these engineered containment techniques were originally designed for water control during construction and were not intended for use as permanent construction features. Thus there is a basic uncertainty with respect to the longevity of these systems. What is unique with respect to the application of these design principles to pollution control which complicates matters is the chemical interactions that may take place and how these reactions may affect performance of containment techniques. These uncertainties should not be a determent to the application of certain containment technologies. Increasing our understanding of uncertainties will not remove them but will help us calibrate our expectations and make us more aware of inherent risks so we can develop compensating design strategies and provide direction for further research.

This paper examines state-of-the-art containment technologies as well as their inherent uncertainties as we understand them today. We examine conventional as well as new approaches to contain hazardous waste sites, and conclude with some recommendations on how to deal with the uncertainty in the engineering containment of these sites.

Background

There are four classes of chemical waste streams commonly encountered at hazardous waste sites: (1) aqueous inorganics where water is the solvent and solutes are mostly in the form of inorganics such as metals dissolved in inorganic acids, e.g. electroplating waste; (2) aqueous organics, also a water soluble waste containing polar or chaped organic chemicals, examples include wood preserving waste and pesticide container rinse water; (3) organic solvents with dissolved chemicals such as oil based paint waste and spent cleaning solvents; and (4) sludges from waste processing and filtering of solids that may include clay minerals, silts, fine solids, chemical precipitates, and high molecular weight hydrocarbons. From these four types of waste, leachate may be formed which would include some combination of waste fluids and the water soluble portion of the waste generated through water percolation and leaching of the waste.

Typically, drummed waste and heavily contaminated materials are removed from the site, and there is an entire spectrum of technology under development to treat, alter, or contain such waste so that it is rendered harmless or suitable for disposal. The remaining challenge of the Superfund program is then the remedial aspects of dealing with the large volume of soils and ground water contaminated through leachate migration. Except for extreme conditions or special circumstances, receiving surface water bodies such as streams and rivers will typically tend to cleanse themselves once the source of contamination is removed or contained.

There are basically two approaches to contain or isolate contaminants in soils or ground water: (1) by encapsulation of the zone of contamination or construction of barriers to potential contaminant migration, or (2) bulk or mass stabilization. The former may include some combination of covers and vertical barriers to ground water movement aimed at reducing the rate and amount of water movement into and through the zone of contamination. The latter involves physically or chemically altering the form of the contaminated soil and waste material by mixing it with a stabilizing or neutralizing agent, or through in situ treatment so as to increase its leach resistance and to reduce the solubility of contaminants.

Encapsulation and construction of barriers

Covers

A properly designed and maintained cover system reduces perculation and leachate formation, prevents contaminated dust emissions and contaminated surface runoff. Covers are typically designed as multilayer systems consisting of low permeability soils, concrete, asphalt or synthetic geomembranes as a hydraulic barrier. Components typically include a prepared foundation layer, the hydraulic barrier layer, a drainage layer to intercept percolating water and to channel it away, and a surface layer to provide for vegetation growth. There has been increasing interest in the need for a biotic barrier to prevent animal and plant roots from penetrating the hydraulic barrier. However, such a barrier has not yet been installed at a site, even though research results indicate that a layer of cobbles or other coarse materials may be effective as such a barrier [1,2].

Cover performance uncertainty

There are two types of concerns with respect to the performance of covers. One is our ability to predict the environmental conditions under which the cover must perform, and the other is predicting the chemical and mechanical integrity of the cover system under these conditions.

Environmental factors that must be considered in design include surface drainage and near surface soil and ground water conditions, freeze—thaw cycles, subsidence or differential settlement due to waste consolidation or biodegradation of waste or corrosion of containers, and the threat of burrowing animals, plant roots, or even human intrusion as a result of the transfer and development of contaminated properties. Another environmental factor that has a most profound effect on the performance of a cover system relates to the local hydrologic system. Experience has shown that the near surface hydrogeology of a site is very difficult to characterize because it is so strongly impacted by minor changes in geologic conditions and changes in season. Ground water levels can fluctuate and the mechanisms for ground water movement are different and more complicated under unsaturated as opposed to saturated flow conditions. Disturbances of the area from waste management activities and even construction of a cover will alter the local hydrologic system. As with any other engineering problem, our approach to design would be to consider the range and combinations of environmental conditions expected and the uncertainty in those projections. But we need to be careful. Our experience has been that we sometimes have an oversimplified view of the situation. For example, we may discover a detail that turns out to be important to performance but was not adequately accounted for. Our best defense is to never lose perspective that our conceptualization and model of a site is always a simplified characterization of the situation and that any conclusions we draw from analyses are not likely to be any more accurate than the data what went into it.

The areas of greatest uncertainty with respect to cover performance have more to do with construction and the durability of barrier materials contained in the cover system. Soil layers are subjected to cracking due to subsidence, dessication, or freeze—thaw cycles. Even though we can produce high quality concrete, we can experience a leakage problem at construction joints. Asphalt-based materials were used several thousand years ago in sealing early canals and aqueducts. Yet our experience shows that it is difficult to control the uniformity of mix temperature, compaction effort, and the final thickness and density of asphalt concrete over large areas. It is difficult to get complete coverage with sprayed-on water barriers due to small protuberances. Also, historically there are problems of long term deterioration of concrete and asphalt due to attack by dissolved salts and icing conditions. Asphalt is also subject to attack by organic solvents [3].

Synthetic polymer membranes, which are now most popular, are promising particularly with respect to the problem of chemical resistance. They include a wide range of vulcanized and nonvulcanized thermoplastics, plastics and rubbers. A combination of materials is often utilized to provide protection against most conceivable types of problems. The most significant difficulties are that polymer membranes are subject to punctures and tears during construction and they often require field seaming which is a difficult process to control. Finally even though these liners are durable, there is some concern with regard to their long term integrity. Many of these liners have plasticizers to give them tensile strength to resist tearing during construction and differential ground movement due to localized settlement. Limited experience shows over time that some of the plasticizer may be lost due to volitization, chemical leaching, and microbiological attack [3]. Significant research is ongoing in the development of chemically resistant polymer membranes as well as the simulation of hazardous waste liner applications in the laboratory and the field.

Vertical barriers

The need to control contaminant migration from hazardous waste sites has resulted in the application of slurry trenching and cutoff or diaphragm wall technology. Quite often such vertical barriers are designed in conjunction with a cover system. Slurry trenching is a technique of excavating a deep narrow trench while maintaining a bentonite water slurry to support the sides. The cutoff or diaphragm is then constructed by backfilling the slurry trench with bentonite often mixed with native soils. Alternatively, the trench may be excavated and held open using a mixture of Portland cement and bentonite which is then left in place to harden and form the final wall. Also structural diaphragms may be constructed by installing precast or cast-in-place reinforced concrete panels during slurry trenching. Combinations of these approaches may be used, e.g., synthetic membranes may be placed within a cement bentonite backfill before it hardens so as to lower the permeability of the wall or to increase its resistance to chemical attack. Depending on site conditions, walls may be keyed into underlying low permeability geologic formations or may only penetrate deep enough to allow capture and recovery of organic contaminants floating on top of the water table. Grout curtains may also be used in conjunction with a slurry wall to provide for cutoff in fractured rock, and sheet piling may be used to protect a wall from stream erosion.

Slurry wall construction originated some 30 years ago as a method of providing water seepage control in the foundation of earth dams and was later applied to provide for seepage control in dewatering excavations. The technique was first adopted in the construction of pile and caisson foundations and eventually led to the development of cast-in-place continuous concrete diaphragm walls. Slurry walls were initially used as temporary or remedial structures and were considered dangerous as permanent structures due to concern for their potential for inducing differential settlement and cracking of earth fill dams. More detailed discussion of the history and application of slurry walls may be found in EPA's handbook, Slurry Trench Construction for Pollution Migration Control, published February 1984 [4].

Slurry wall performance uncertainty

There are three major areas of concern with respect to the performance of slurry walls: (1) potential risk of defects inherent in the construction technique; (2) risk of differential settlement and hydrofracturing resulting in separation of soil layers; and (3) chemical deterioration caused by compatibility problems.

The bentonite slurry provides two important functions: (1) it coats the sides of the trench with a thin slippery layer called a filter cake which limits seepage into or out of the trench during construction; (2) bentonite has extensive dispersity properties so the slurry can be made sufficiently dense to hold the trench open. The bentonite slurry forms a gel when allowed to stand undisturbed. A "house of cards" structure is formed between positively charged clay particle edges and negatively charged surfaces, and this structure allows soil particles to be held in suspension. It is the weight of the slurry against the filter cake that holds the trench open.

The most common construction defect is the presence of pervious material in the final wall or the lack of a tight cutoff at the base. These conditions can result from loss of pervious soils from the sides of the trench or the accumulation of course sediments on the bottom. Also, some have suggested that pockets of bentonite water slurry may be trapped during backfill placement [5].

Soil bentonite backfill is typically placed at a consistency of high slump concrete. The walls of the slender trench will provide shear resistance to the settlement of trench backfill so that the consolidation of the backfill could result in separation of soil layers as a result of bridging within the backfill. The potential for such separation may also be enhanced if the effective compressive stress in the backfill falls below the hydraulic pressure in the pore fluid of adjacent geologic formations, resulting in hydrofracturing.

In spite of these concerns, slurry walls have performed very well for most applications. There are design and construction quality control measures that can be taken to reduce these uncertainties to manageable levels. The concern that is unique to the application of slurry walls to pollution control is the chemical compatibility of the bentonite in the backfill with the contaminants. Unfortunately, there is limited information available on soil—bentonite—waste interactions in slurry wall construction. Certain chemicals have been shown to have an adverse effect on bentonite and Portland cement. Most studies have been performed on natural clays and on a site specific basis. Therefore, care must be exercised in extrapolating results to other sites. Also, most studies have been performed on specific compounds and there is uncertainty with respect to synergistic effects where multiple compounds are involved. Also there may be problems in scaling the results of laboratory studies to field applications. Particular areas of concern are adverse affects on permeability [6—20]. Finally, most applications have been in the private sector so field data are not readily available, and most have been in place for a relatively short period of time so there are limited data on long term performance.

Bentonite clay crystals (sodium Montmorillinite) are platelets made up of two outer layers of silicon and oxygen molecules. Sandwiched between is a layer of aluminum atoms surrounded by hydroxyl or oxygen atoms. Because of substitutions of atoms in these three layers, there are unsatisfied bonds existing within the crystals giving the polar clay crystal a high net negative charge. Cations and water molecules are absorbed onto the internal and external surfaces of the Montmorillinite clay crystals until the cations satisfy this charge. As the clay crystal is hydrated, water molecules are absorbed causing it to expand in volume. The cations tend to move around in the liquid layer forming a positively charged cloud around the clay particles. The clay particles will absorb water until the net negative charge on the clay surface is neutralized. Dry bentonite can swell to 20 times its original volume during hydration. The actual amount can be affected significantly by the cations present, sodium being the best.

In typical slurry trench applications, the soil bentonite is mixed with native soil to produce the backfill slurry. After the soil bentonite is mixed with native clay soil or cement and is in a fully hydrated state, the bentonite will be effective in filling the voids to reduce permeability. It has been suspected and demonstrated in the laboratory, however, that a deterioration or increase in permeability occurs as organic fluids displace the pore water in a soil bentonite layer [6].

Organic fluids do not transmit a charge as well as water, and thus the thickness of the layer of liquid containing the cations must be decreased for the negatively charged clay surface to be neutralized by the positive charge of the cationic cloud. As a result, interparticle spacing decreases, resulting in a increase in permeability that is directly proportional to concentration.

Work by Brown and Anderson with respect to the effects of organics on clays suggests that in some cases there may be structural changes involving particle rearrangement in addition to changes in interlayer spacing [7]. Brown and Anderson also found that organic acids affected permeability by still another mechanism. Certain organic acids dissolved soil particles breaking them down. This was followed by piping of the particle fragments through the soil. Unfortunately, there are limited field data at this point. However, as a minimum, these investigations support the need for extensive site specific testing and long term monitoring.

Bulk or mass stabilization

Mixing techniques

An alternative approach to containment is to stabilize contaminated soils by solidifying it; i.e. microencapsulation of the fine waste particles and binding the waste into a monolith. Contaminant migration is reduced by vastly decreasing the surface area exposed to leaching.

There are three basic approaches to solidification of the waste: (1) mixing the waste with absorptive materials to take up the free liquid; (2) use of lime on Portland cement to provide a "cementation" to further aid in solidifying the waste and reducing its leach resistance; and (3) solidification by mixing dried waste with thermoplastic materials such as asphalt, polyethylene, or polypropylene. Sorbent materials to mix with the waste include natural soils, fly ash, cement or lime kiln dust as well as synthetic materials including glass, polymers and treated soils.

Many stabilization application can be accomplished using a mixing pit and backhoe. If more thorough mixing is required, a pug mill or ribbon blenders may be used. Many types of water-based slurries may be mixed with cement using cement mixing equipment. Large solidification projects may use a batch mixing plant. Extremely hazardous waste may be mixed in drums. Blended materials may be compacted to increase its density and disposed on site or it may be placed in a landfill. If cements are used, the material may be compacted into molds and allowed to cure before disposal. In situ mixing is most suitable for closure of liquid and sludge holding ponds and mobile mixing plants are preferred where large quantities are involved. Area mixing consists of spreading in layers at the final disposal site and mixing in place. A more thorough discussion of these stabilization techniques is presented by Spooner [21].

Expected performance

Most soluble multivalent toxic metals can be transformed into low solubility hydroxis or carbonates by the high pH of the mixture. Where pozalan materials are used as a mixing agent contaminants may become integrated into the mineral crystals within the cement. Areas of concern include uncertainty with respect to the homogeneity, permeability and leach resistance of the stabilized mass under site conditions. Large stabilization operations raise other concerns, e.g. heat generation from hydration may result in volitization of contaminants and dust propagation and there is a question with respect to the physical stability and strength of the mass to support a cover. Other concerns include the reactivity of waste with landfill liner materials and other waste, and the ignitability of waste solidified in thermoplastic and methane generation as a result of biodegradation of waste.

In situ techniques

An alternative approach to mass stabilization of contaminated soil or ground water is to treat in place using chemical or biological agents to immobilize, remove or degrade the contaminants. In situ treatment technologies are not well developed, however some techniques have been successful in the clean-up of spills and others show promise in the laboratory. Such techniques require injection of agents into the subsurface and thus are more applicable where there is coarse grained, higher permeability soils. Even then, closely spaced injection wells are often required. Immobilization of contaminants can be achieved by: (1) precipitation, e.g. divalent metals cations can be precipitated using sulfide, phosphates, hydroxides or carbonates; (2) polymerization, e.g. fluids may be transformed into a gel by injection of an organic monomer; and (3) sorption, e.g. organics may be injected to enhance the natural sorption properties. Contaminants can also be removed by flushing the soil with water or an aqueous solution to flush water-soluble on water-mobile organics and inorganics. Water or an aqueous solution is injected into the contaminated area and recovery wells are placed to remove the contaminants and to allow recirculation of the flushing solution. Finally, oxidation reduction techniques, where oxidizing agents such as hydrogen peroxide and ozone are injected into the ground to chemically alter or detoxify organics have been accomplished in the laboratory. There are standard waste water treatment technologies being applied for groundwater treatment, however, the concentration levels in ground water are typically low and there is uncertainty as to the efficiency and cost effectiveness of some techniques. Biological treatment techniques have also been demonstrated in the laboratory and in waste water treatment processes. The feasibility and effectiveness of the bioreclamation process at depth, however, is even more tenable than chemical stabilization processes, in that it is affected by the biodegradability of the organic contaminants and a host of other environmental factors that affect microbial activity. Also, the rate of ground water movement must be sufficiently high and the residence time short enough so that the oxygen and nutrients are not up before it reaches the contaminant zone of interest. A more thorough discussion of in situ techniques is presented by Wagner [22,23].

In situ techniques are in general difficult to implement because they require pervious soils that will allow injection and permeation of a treatment solution whether it be chemical or biological. Also it is difficult to design an approach that will deal with all the site complexities. A treatment method that immobilizes one contaminant may mobilize another; a flushing solution that mobilizes another may increase the toxicity of another and so on. In spite of the uncertainties, in situ approaches have merit and should be considered but preferably in combination with more conventional techniques.

Dealing with uncertainty

The current limitation in the state-of-the-art of any particular containment technique or uncertainty in its performance should not be considered the reason for not applying such an approach. To the contrary, it should spur interest in advancing our knowledge of such approaches. Current proven technology was once innovative technology, and even proven technology applications must be demonstrated at each site since performance is so directly related to site specific circumstances.

How should we then apply these techniques? First, we must accept that no system will provide total containment. Combinations of system features can, however, be designed to provide an adequate degree of protection. To the degree practicable, we should design our containment systems using techniques that have been demonstrated under similar circumstances so as to minimize uncertainty. We should tailor the design of contaminant systems features to site specific conditions considering geologic, hydrologic and geochemical conditions as well as issues of chemical compatability. Whenever possible, we should include in the system design complementary features that serve to reduce or compensate for uncertainty, e.g. use of subsurface drainage systems in conjunction with slurry walls. Secondly, we should become more familiar with the innovative technology available and we should look for "opportunities" to complete demonstrations of approaches that are at the threshold of field application. Opportunities exist at sites where conditions are particularly suitable for an approach and where we can combine an innovative containment technology approach with a more conventional technique that is demonstrated but based on a different principal. For example, it may be worthwhile to consider applying an in situ treatment approach where we are using a slurry diaphragm wall to encapsulate the zone of contamination — thus we would be combining mass stabilization with encapsulation. Each approach will provide compensation for uncertainty in the other and new performance data will be developed. Thirdly, we should plan a monitoring program to collect data that demonstrates performance or tells us where the system may not function as planned and designed. Monitoring should be aimed at measurement of specific key parameters that relate to failure mechanisms and not just the end result of contaminant migration. We need to make performance information available to those making decisions on other sites and provide feedback on "lessons learned" into the research community so that we can focus on the refinement in our understanding of those techniques and the resolution on problems identified.

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