Innovative Design Concepts for Leachate Containment and Collection Systems

J. W. Cowland
Geotechnical Engineering Office, Kowloon, Hong Kong

L. K. Overmann
Golder Associates Inc, Atlanta, GA, USA

ABSTRACT: The applicability of standard landfill liner design is reviewed for the South-East Asian situation. A more performance based design approach is suggested, which would allow the development of new geosynthetic products for leachate containment and collection systems.

1. INTRODUCTION

The circumstances prevalent in large parts of North America, and in parts of Europe, have led to fairly standardised landfill designs. Due to environmental concerns, regulators have adopted control over the materials used, especially in leachate containment systems. The standard landfill liner comprises layers of clay, or bentonite amended soil, or bentonite mats, and geomembranes. The leachate collection layer usually comprises either a geonet or a coarse granular material.

These standard designs originated in relatively flat areas, and were conceived as near horizontal layers. However, many parts of South East Asia are mountainous regions where landfills are often placed in steep sided valleys, or canyons, where the horizontal portion of the liner may be only a relatively small proportion of the overall site. In addition, annual rainfall in many parts of South East Asia is considerably higher than in other parts of the world, allowing the formation of surface reservoirs for drinking water. As a result, these regions are not as dependent on groundwater supplies as those countries where the standardised liner designs originated.

Using a performance based approach, in which careful consideration is given to the necessary level of protection to groundwater, surface water and sea water, it is possible to produce innovative landfill design concepts. These site specific innovations will stimulate the development of new approaches to using existing geosynthetic products, and also the development of new geosynthetic products for leachate containment and collection systems.

2. PERFORMANCE BASED DESIGN APPROACH

In a performance based approach to landfill leachate containment, the design is based on the hydrogeologic setting, the allowable concentrations of possible contaminants in the groundwater, and the engineering properties of the liner and leachate collection system materials.

If the design of a leachate containment and collection system is based on a performance analysis, rather than a regulator's imposed sequence of layers and material standards, then the design begins at the first point of use of the ground, surface or sea water. The first step is to determine the existing, and the necessary future quality, of this water resource. The necessary water quality is likely to be defined in a drinking water standard, a health standard (eg. World Health Organisation standards), an agricultural use standard or a bottling standard. The application of the selected standard could be based on either the existing or the future use of the water.

The next step is to determine the volume of water flowing out from the landfill site area. In a properly engineered landfill, surface water is usually carefully controlled, but, nevertheless, possible escapes of contaminated surface water should be considered. However, for many situations we are typically interested in measuring only groundwater flows beneath the landfill. In order to be representative of dry periods, the base, or low, flow should be determined. This base flow is the volume of water which will dilute the outflow from the landfill.

No matter how well a landfill leachate containment system is designed and constructed, there will inevitably be some leakage, although usually only a small amount. As long as any possible contaminants can be diluted in the groundwater to a level below the relevant water resource standard, then this need not necessarily be a cause for concern. A possible small outflow of liquids from a landfill could be viewed in the context of other liquids that can contaminate a water resource, for instance the chemicals that are annually sprayed onto agricultural land.

It is necessary to trace the groundwater flow back from the first point of use to the area beneath the containment system. The first point of use may be a down gradient agricultural irrigation well, a drinking water well, a surface water stream, or, in the case of coastal landfills, the sea. In the most conservative instance, anticipating adjacent future development, the point of first use is often assumed to be the landfill property boundary. In tracing back, additions and losses to the flow (eg. infiltration of surface water) should be included. Thus, the allowable leakage of the containment system can be determined, and on this basis alternative systems can be evaluated.

3. COMPONENTS OF THE LEACHATE CONTAINMENT SYSTEM

The containment system for a steep sided valley landfill can be divided into two components - the base and the side slopes. It is expected that leachate will rest for a period of time on the relatively flat base of a valley landfill. However, if good drainage is provided, then the duration of contact with the side slope liner may be relatively short. The side slope liners may therefore only have to cope with wet period flows of leachate. Thus, the base and side slope containment systems can be analysed and designed separately, and the estimated outflows can be determined on a prorata basis.

The outflow of leachate through a containment system will be a function of the area of the liner, the head of leachate in contact with the liner, the hydraulic conductivity of the liner, the numbers of liners in the system and the chemical resistance of the liner to deterioration from exposure to the leachate. As the head of leachate in contact with the liner is the driving force for any leakage from the containment system, the leachate drainage layer is a vitally important component of this system. If the leachate can be rapidly conducted away from the liner, then possible leakage through the liner becomes less of a concern.

4. SIDE SLOPE LEACHATE CONTAINMENT SYSTEMS

Many topographic and geologic settings allow the formation of very steep side slopes to a landfill. Where rock is present, the side slopes can be cut to be near vertical. With adequate leachate drainage, it is considered unlikely that the entire area of a very steep sidewall liner would be wetted at any one time. It is more likely that leachate would flow over the sidewall containment layer in the form of discrete streams, resulting in a significantly reduced wetted area through which leakage could occur. In general, a low hydraulic head of leachate would act on the liner and an innovative design could be produced.

In Hong Kong, many landfills have been sited in steep sided valleys. In these landfills, waste is placed against the valley slopes, and a slope of landfilled waste is formed at the mouth of the valley. In this situation, the aim of the leachate collection system is to effectively husband the leachate down the valley to a point where it can be treated or taken away. With the need to excavate for materials onsite (eg. daily cover, haul road sub-base, and crushed rock drainage layers), and the advantages of creating more air space with these excavations, the valley side slopes have been steepened.

As Hong Kong progressed from the philosophy of dilute and disperse to containment, the first crude designs for side slope liners included steepening the natural valley slopes (which are often up to 40° from the horizontal) and applying a sprayed liner (shotcrete). Crushed granitic rock drainage materials were then placed as a leachate collection layer against these liners as the waste was deposited (Cowland, 1991). It was thought that as long as the drainage material remained an order of magnitude more permeable than the liner, then the leachate would prefer to drop vertically down the drain rather than pass horizontally through the sidewall. A recent environmental study of a landfill incorporating one of these crude containment systems did not detect any significant groundwater contamination.

The next generation of side slope systems in Hong Kong has included cutting, or quarrying, the slopes to produce near vertical excavations in rock which are to be lined with geosynthetics. A great deal of effort is being expended on producing smooth, planar, rock slopes which are suitable surfaces to simply roll out the currently used geosynthetics. For instance, at one landfill, no-fines concrete is being cast as a ground water drainage layer against the rock faces, using expensive formwork to create a smooth surface. At another valley landfill, considerable expense is being incurred to form planar rock faces, using precision pre-split blasting techniques. The necessary final smooth surface that is required for the geosynthetics is being formed by applying varying thicknesses of shotcrete, and then a geotextile cushion.

It is interesting to note that in similar conditions on the other side of the Pacific, at the Los Angeles Lopez Canyon Landfill, the materials specification prescribed in the regulations rendered construction of the liner technically and economically prohibitive. Instead, an innovative alternative design was eventually approved due to the city's urgent need for additional waste disposal capacity (Derian et al, 1993). This also included shotcrete to form a smooth surface for the geosynthetics, although here it was given the more environmentally sensitive name "reinforced air-sprayed slope veneer".

4.1 Innovative Products for Side Slopes

There is undoubtedly scope to produce geodrains for the groundwater drainage layer that can be placed on a less smooth surface, to save considerable expense in forming planar slopes. In addition, the relatively thin nature of the geonet that is currently used for drainage raises the question of the adequacy of its transmissivity, particularly when placed under the increasing depths of waste that are being planned (now up to 180 metres). Perhaps it might be possible to produce thicker and more flexible geodrains, with greater load carrying and flow capacity for these situations. Additionally, there may be a need for a geodrain which is capable of withstanding high tensile forces, perhaps a combined geodrain and geogrid.

Having formed a smooth very steep slope, there are still difficulties involved in fixing geosynthetic clay liners (GCLs) and geomembranes to it. There is a need to develop GCLs where the bentonite powder cannot migrate downslope through the material, and also GCLs that have a better internal angle of friction. A very good review of the current state of development of GCLs for steep slopes is contained in Byrne (1994).

Whilst it is relatively easy to roll a geomembrane down a near vertical slope, it is less easy to weld the rolls together, and even more difficult to carry out quality control (QC) testing and quality assurance (QA) monitoring. For instance, it is extremely difficult to perform the standard vacuum box test on a near vertical slope. In order that the operatives spend as little time as possible dangling from ropes, better welding techniques are required, which might result from using geomembranes with larger welding temperature windows.

The method of fixing the complete sandwich of geotextiles, geodrains, geosynthetic clay liners and geomembranes to near vertical slopes is still evolving. It is necessary to ensure that there is no downslope movement, either during construction or under the subsequent weight of waste, and that the geomembrane does not become ripped or punctured.

5. BASE LEACHATE CONTAINMENT SYSTEMS

It is now common in southern China for a depth of 50 to 100 metres of waste to be placed in landfills. Indeed a landfill with only 50 metres depth of waste is regarded as being relatively small. Two landfills in Hong Kong have 120 metre depths of waste, two more of that depth are being formed, and one is planned to have 180 metres depth of waste. Due to the warm climate, and the decomposing waste, the temperature of the leachate in these landfills is anticipated to be quite high (Overmann et al, 1993).

As mentioned earlier, the leachate collection system on the base is part of the liquids management system which is needed to husband the leachate into a treatment system. Leachate collection systems usually comprise either drainage layers of gravel protected by geotextile filters, or thin geodrains with an internal geosynthetic net structure sandwiched between two layers of geotextiles. Plastic pipes are typically placed at intervals within the system to conduct the flow of leachate away.

The concept of using these materials for leachate collection systems originated from very much smaller, and less deep, landfills. Koerner et al (1993) describe some cases where the geotextiles have become clogged, and the pipes have become crushed. The permittivity of geotextiles decreases with increasing normal stress, due to increased load, and therefore their tendency to clog increases. The ability of the current range of geonets and plastic pipes to continue to function effectively under large crushing loads needs further consideration for landfills with 180 metres depth of waste.

5.1 Innovative Products for the Landfill Base

There is undoubtedly scope to produce stronger geodrains with a larger internal flow capacity, and an increased geotextile permittivity, to give the designer more confidence in the long term performance of the leachate collection system beneath a large landfill. There is also scope to redesign plastic collection pipes, so that they may resist a greater weight of overlying waste. Perhaps some form of ribbing could be used to strengthen them. At the same time, the effect of relatively high leachate temperatures (often around 45°C.) needs to be considered for all these products in view of the tendency for some polymers to creep.

6. RECOMMENDATIONS

The design of environmentally safe landfills for the disposal of waste has evolved very rapidly over the last two decades. With ever changing circumstances, this design process needs to be allowed to continue to evolve. Rather than precisely specifying the materials to be used, and the methods of installing these materials, the design of leachate containment and collection systems needs to be based more on the required performance of specific sites.

With ever increasing depths of waste being placed in landfills, and the advantages of using steeper containment system side slopes, there is scope to develop and produce new geosynthetic products for leachate containment and collection systems. These new products might include:

- stronger, less crushable, geodrains with a larger flow capacity;
- geodrains that can be placed on rough surfaces (to save the expense of forming smooth planar steep slopes);
- geosynthetic clay liners with improved friction characteristics, both internally and externally, for use on steep slopes;
- geomembranes that are easier to install, seam and test, on near vertical slopes; and
- stronger plastic pipes.

REFERENCES

Byrne R.J. (1994). Design Issues with Strain-Softening Interfaces in Landfill Liners, *Proceedings of Waste Tech '94*, National Solid Wastes Management Association, South Carolina, USA, Sect. 4, pp. 1-26.

Cowland J.W. (1991). The Design of Liner Systems for Hong Kong Landfills, *Proceedings of Polmet '91, Pollution in the Metropolitan and Urban Environment*, Hong Kong Institution of Engineers, pp. 169-186.

Derian L., Gharios K.M., Kavazanjian E. & Snow M.S. (1993). Geosynthetics Conquer the Landfill Law, *Civil Engineering*, December, pp. 50-53.

Koerner G.R., Koerner R.M. & Martin J.P. (1993). Field Performance of Leachate Collection Systems and Design Implications, *Proceedings of 31st Annual Solid Waste Association of North America Conference*, California, USA, pp. 365-380.

Overmann L.K., Cowland J.W., Mattravers N.K., Shung W.K., Lee B.S. & Wan C.H. (1993). Chemical Resistance Testing of Liner Materials for Hong Kong Landfills, *Proceedings of Fourth International Landfill Symposium*, Sardinia, Italy, pp. 333-347.

ACKNOWLEDGEMENT

This paper is published with the permission of the Director of Civil Engineering of the Hong Kong Government.