

Principles of Locating, Designing and Constructing Landfills of Hazardous Waste

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Abstract

Location, design and construction of a landfill of hazardous waste are in focus. The selected site must be physically stable, and an elevated area with good run-off conditions of precipitated water and tight underground is preferable. The detailed design must adaptate to what legislation requires and be decided on the basis of the required operational lifetime. Several concepts have been proposed and two major principles are compared: 1) location above ground on a drained base with a tight top liner and a less tight bottom liner, and 2) placement below ground with clay liners surrounding the entire waste mass. In either case collection of percolated water can be arranged but maintenance over several hundred years cannot be guaranteed. A design that totally eliminates percolation of the waste is ideal but a number of functions of such concepts need to be considered.

Keywords: hazardous waste, landfills, clay-based isolation, erosion protection, climatic impact, location

1 Location of Landfills

The crucial point in locating and designing landfills of hazardous waste is that it must be shown that contaminated water from percolation of the landfill does not generate unacceptably high concentrations of hazardous chemical species in the groundwater. Regulators have defined the limits and the type of waste determines how effectively it must be isolated and there are good examples of successfully constructed and performing landfills that contain elements of heavy metals and solidified liquid waste like pesticides. Low-level radioactive waste, including DU as described in Workshop papers, belong to the group of potentially hazardous waste and they may require extra barriers for minimizing risks.

The siting of hazardous landfills depends primarily on the required operative life-time, design principle and expected performance of the engineered barriers. A number of criteria need to be considered like:

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socio/economic and infrastructural conditions: these may be unsuitable and determine whether the intended region can be exploited at all for the intended purpose,

stability of ground: deposition of potentially hazardous waste shall be made on ground where general stability prevails, requiring that the topographic conditions must be acceptable throughout the specified operative lifetime of the landfill considering exogenic impact, which makes prediction and assessment of all relevant physical, chemical and biological processes in the area necessary. They include:

- tectonics or seismic events causing disturbances,
- ground or slope failure caused by the load of the landfill and confining dikes,
- exogenic impact by extreme precipitation, comprehensive rock fall from adjacent steep hills, and large-scale slope failure),

effective run-off of rain and meltwater: if the planned area is subhorizontal there is need for a) removal of vegetation and organic soil, b) placement of self-draining fill before the landfill is constructed); c) excavation of ditches for placing lasting (ceramic) drainage tubes in sand/gravel/boulder fill, with soil filters in contact with surrounding, natural soil. The filters are needed for avoiding clogging of the tubes that are responsible for discharge of drained water to a nearby lake, river or major creek,

- 1) *settlement*: submergence of a landfill can cause uneven settlement and accumulation of rain- and meltwater on the top of the landfill, accelerating percolation of liners and waste mass. Geotechnical data from borings (sounding and sampling) and determination of the shear strength and compressibility of undisturbed samples are requested for deciding whether the site is suitable for constructing a landfill,
- 2) *flow of percolated water from the landfill*: percolate from the landfill will flow into the underground at a rate and in directions that are determined by the stratigraphy and hydraulic properties of the underground. This means that permeable soil strata can cause contamination of the porewater at large distances from the landfill, and that percolate can enter fracture zones if the landfill is constructed on rock. A rock structure model hence needs to be worked out and used for calculating the flow of the percolate from the landfill area to be discharged in a lake, river or major creek.

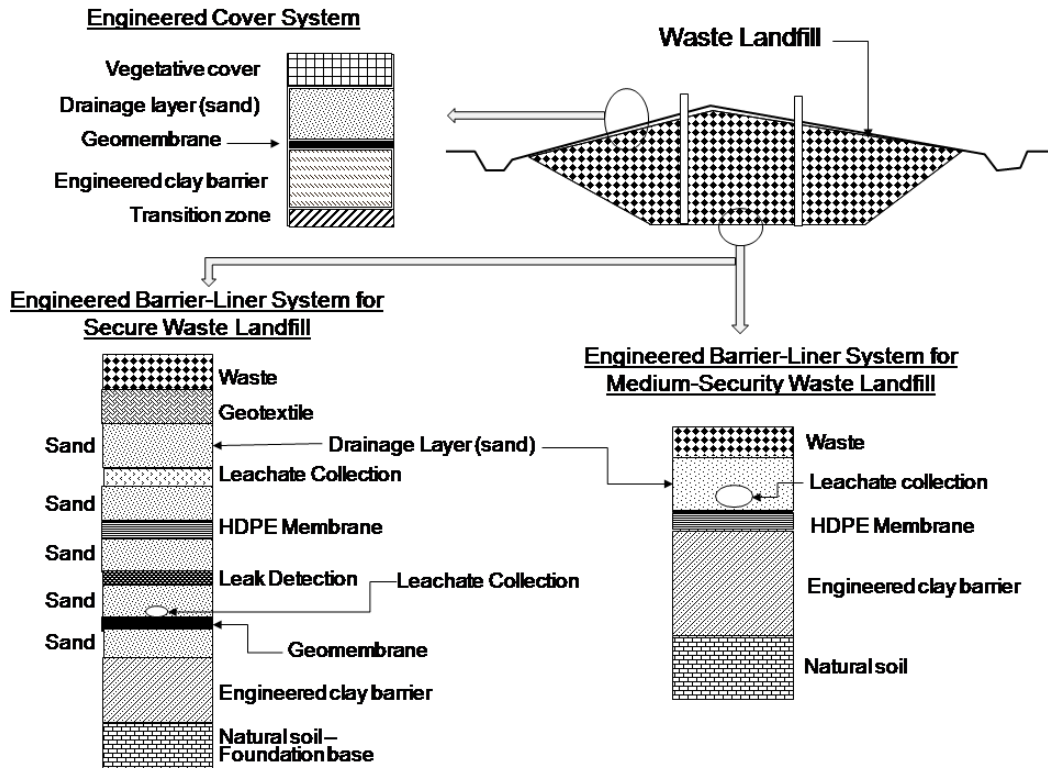


Figure 1: Typical engineered barrier-liner systems for secure waste (e.g. HSX) and medium-security (e.g. MSW) landfills [1]. Note that the thickness of the engineered clay layer overlying the natural foundation base should be: (a) thick enough to provide satisfactory attenuation of contaminants escaping from the landfill, and (b) at least one meter thick [1].

2 Design of Hazardous Landfills

2.1 Principles

Legislation rules the design principle and it is commonly required that landfills should rest on a low-permeable bottom liner and be covered by a top liner with low permeability, in turn covered by erosion-resisting coarse soil. A permeable layer over the bottom liner for leading percolated water to tubes for being collected is frequently required although the function and maintenance of such systems and handling of the percolate cannot be guaranteed over the required, usually 300 year long, operative life-time. Figure 1 shows an example of engineered barrier-liner systems for what is termed secure and medium-secure waste [1]. One realizes that no effective measures are taken to direct rain- and meltwater off the waste and that the composition of the barriers is very complex and difficult to construct.

Location of the waste mass below the ground surface can cause quick water saturation of the waste, by which soluble hazardous species migrate through the bottom liner to the surrounding groundwater.

Figure 2 illustrates a different principle that minimizes percolation of a landfill of

hazardous waste by locating it on the ground surface well above the groundwater level and covering it with a very tight clay liner.

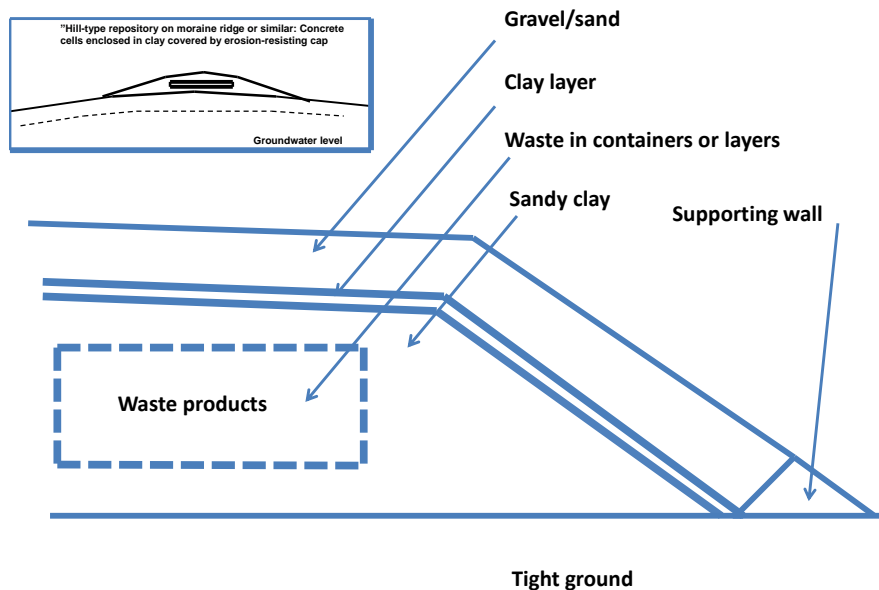


Figure 2: Proposed principle for landfill of hazardous waste on the ground surface following the principle of minimizing or eliminating through-flow of the waste mass. The groundwater level is below the foundation base and the landfill is built on a bed of self-draining friction material (silt and sand over gravel and crushed rock).

2.2 Clay Materials

All the engineered barriers must be properly designed with respect to grain size distribution, density and chemical stability and special emphasis must be put on selecting a suitable material for the clay liners and practical ways of placing it. Several landfill concepts imply that the clay liners shall have a hydraulic conductivity of E-11 to E-10 m/s for giving sufficiently low percolating rates, which requires use of expansive clays since non-expandable clay minerals, like those containing illite and chlorite, do not apply even if they appear in the form of fine-grained moraine clay [2].

Smectitic clay is preferable because its hydraulic conductivity is very low and its self-sealing ability significant in case of desiccation or mechanical disturbance. This is because of the expandability of the smectite particles, which consist of very thin (10 Å) lamellae forming stacks that contain 1 to 3 water molecule hydrates (Figure 3). The hydration of initially unsaturated clay powder grains make them expand and generate shear stresses resulting in exfoliation of thin stacks of lamellae from the grains [3].

The particles interact by carrying a negative charge except at their ends, which means that smectite clay behaves as a colloid with the void size and hence hydraulic conductivity being functions of the salt content of the porewater (Figure 4).

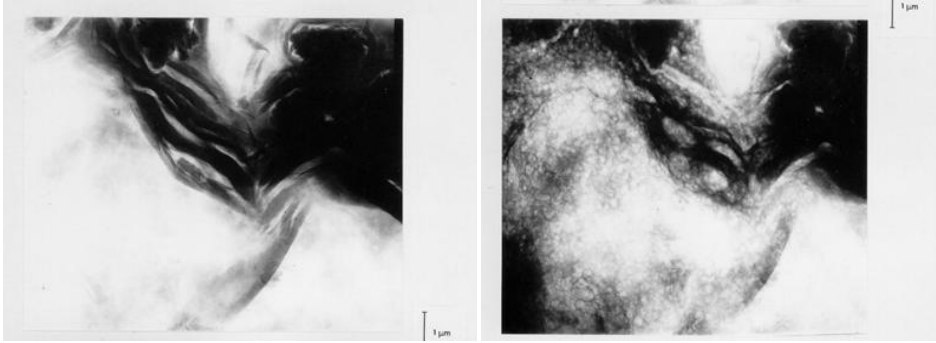


Figure 3: Expansion of air-dry Na smectite clay by exposure to water vapour in a high-voltage transmission electron microscope [3].

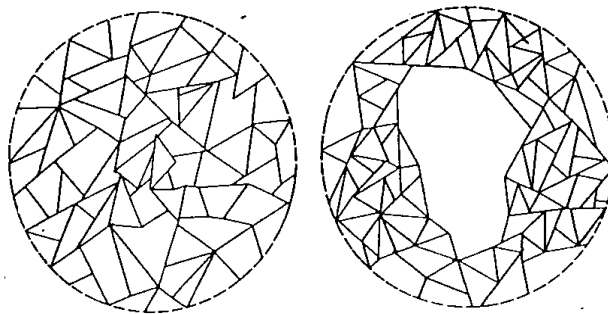


Figure 4: Coagulation of clay particle gel. Left: Structurally homogeneous clay network. Right: Coagulation by increased electrolyte concentration in the porewater [3].

2.2 Possibilities and Limitations

2.2.1 Tight top or bottom liners?

The advantage of smectite liners is that their hydraulic conductivity is very low even at moderate densities while a problem is that even low densities can give critically high swelling pressure. This pressure must not exceed the vertical effective stress caused by the overburden – sand and gravel indicated in Figure 2. The overburden must also provide thermal protection to the clay with respect to frost penetration and desiccation and its thickness must in practice be at least 4-5 m. This gives an effective pressure on the clay liner of 80-100 kPa and a corresponding counterpressure is provided by a clay with 25-30 % smectite and a density of 2000 kg/m^3 . The hydraulic conductivity can be on the order of $E-11 \text{ m/s}$. For less smectite-rich clay or for mixed-layer clays the conductivity can be ten times higher and the swelling pressure three times lower [3]. Clay liners are suitably 0.5 m thick and placed by use of padfoot vibratory rollers.

While a top clay liner must not be too rich in smectite or too dense in order to limit the swelling pressure, a bottom liner can be more smectite-rich and denser if the waste pile is high. For a waste pile thickness of 30 meters and a density of 2000 kg/m^3 the effective stress on the bottom liner will be about 700 kPa and hence make it possible to increase the smectite content to 50 % for the same clay density without risk of unwanted expansion. This would bring the hydraulic conductivity down by one order of magnitude. The problem is, however, that the coagulating effect of saline percolate water, illustrated by

Figure 4, can cause a substantial increase in hydraulic conductivity and drop in swelling pressure. Furthermore, chemical reactions controlled by pH, as exemplified by using Portland cement for stabilization of the waste mass, may cause dissolution and loss of clay [2,4].

Gas production and migration is a problem for top liners since gas pressure that exceeds the swelling pressure will create channels or upheaval. Ideas have been proposed of how vents can be designed and installed but their actual performance has not been proven [1]. This all speaks in favour of selecting a landfill design with a top liner being as tight as possible and a less tight bottom liner, the principle being that water is kept out from the waste and causing minimum contamination of the groundwater [5]. Gas problems will not emerge either. However, climatic conditions can create difficulties with the tightness and the key questions in this respect are:

1. Can one predict with certainty how daily, weekly, and yearly migration of infiltrated water takes place in a top clay liner with respect to cyclic variations in temperature?
2. Can desiccation create permanent fractures in a top liner?
3. Can chemical changes induced by precipitation of air-borne salt or interaction of non-expanding components reduce the self-sealing capacity of the smectite component?
4. What are the criteria for long-term stability of sloping clay liners considering the influence of desiccation/wetting and creep processes?

All these issues are still under consideration as illustrated by the written contributions to this Workshop and require laboratory testing under controlled conditions and field experiments for creating a basis for working out valid theoretical models of the various processes. This is in fact a difficult matter since it raises the question of if and how instrumentation shall be installed and how it can affect the processes that are supposed to be recorded.

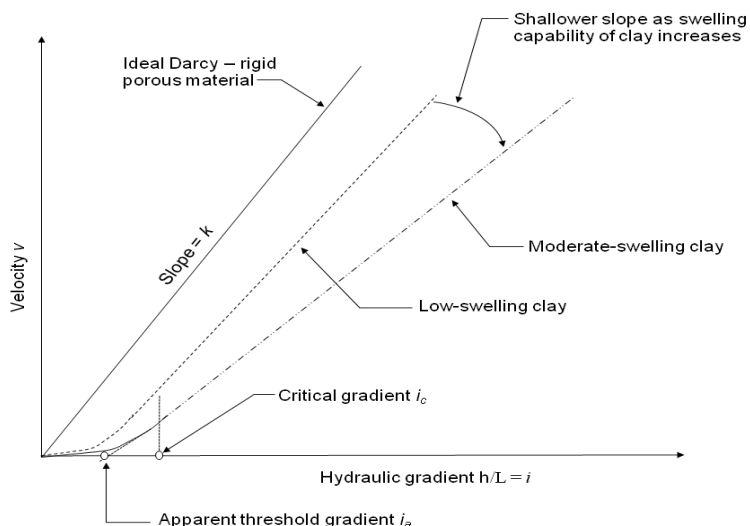


Figure 5: Illustration of critical and apparent threshold gradients obtained in hydraulic conductivity tests on low to moderate-swelling clays [1].

2.2.2 The role of hydraulic gradients

An issue of fundamental importance but not yet fully investigated is the role of the

hydraulic gradient. It will be very low, i.e. on the order of 1-5 m/m (meter water head per meter flow length) for a top liner after complete water saturation and a few tens of m/m for a bottom liner. The matter has been discussed through the years and investigators like Hansbo [6] have shown that Darcy's law, implying linear relationship between hydraulic gradient and evaluated hydraulic conductivity, is not valid for very low gradients in illitic clay (Yong, 2010). Later evaluation of relevant experiments have led to the schematic diagram in Figure 5, indicating that the deviation from Darcy's law may be particularly important for smectite clays. Closer investigation of this issue can lead to deepening of the insight in the flow-related mechanisms and to recommendations of selecting relevant hydraulic gradients in performing percolation experiments and oedometer testing.

3 Conclusions

One of the most important issues in constructing a landfill of hazardous waste is to find a suitable site. From technical and environmental points of view a physically stable, elevated area with good run-off conditions of precipitated water and tight underground is preferable. The detailed design has to be decided on the basis of required operational lifetime and comparison of two principles is described in this paper: 1) location above ground on a drained base and with an effectively tightening top liner but no or less tight bottom liner, and 2) underground placement with clay liners surrounding the entire waste mass. In either case collection of percolated water can be arranged but maintenance over several hundred years cannot be guaranteed. A design that totally eliminates percolation of the waste mass is ideal but a number of functions need to be considered and further testing is recommended.

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