Multi-criteria assessment of the landfill capping profile, an innovative engineering approach to select capping system

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ABSTRACT: Landfills, when decommissioned / closed, shall be encapsulated / capped by a combination of drainage systems and contamination barriers to minimise adverse effects on the environment to an acceptable level. Capping systems should permanently restrict the uncontrolled release of landfill gas and leachate, as well as the infiltration of precipitation into the waste by effective management of the stormwater runoff from the capped surface of the final landform.
The core elements of the sealing systems were earthen components such as clay as the classic sealing layer and gravel / sand as the drainage layer for water / leachate and gas. These have been known as 'earthen capping' solutions. The earthen components shall be compliant with the installation criteria and constructed to a high standard; however, their long-term effectiveness is often susceptible to factors such as: desiccation cracking, erosion, differential settlement, displacements (especially on slopes and above compressible waste), material availability, interface shear strength, and construction quality control. To overcome some of these issues, various geosynthetic materials have also been developed and utilised in landfill sealing and drainage systems, commonly known as 'Geosynthetic' capping solutions.
In this paper, an innovative engineering approach to select a landfill capping profile has been introduced which utilises the concept of multi-criteria assessment for the capping profile alternatives considering the international standards, Australian landfill design guidelines, local factors and site specific parameters that affect the short-term and long-term performance of the final landform.
Keywords: Landfill capping profile, multi-criteria assessment, geosynthetic capping system

1 INTRODUCTION

When a landfill is decommissioned, it shall be encapsulated (capped) by a combination of contamination barriers and drainage systems. The main purpose of capping of a landfill following decommissioning is to minimise adverse effects on the environment to an acceptable level; therefore the function of a landfill capping system are as follows:

- Contamination barrier: the waste material, landfill leachate and landfill gas are the main three sources of contamination which can be released from a capped landfill. The first function of a landfill capping system is to permanently restrict the uncontrolled release of waste material, landfill leachate and landfill gas.
- Drainage system: the second function of a capping system is to permanently restrict the infiltration of precipitation into the waste material by effective management of the stormwater runoff from the capped surface of the final landform.

Two main approaches to design a landfill capping system for the purpose of contamination barrier and drainage functions are as follows:

- Earthen capping system; and
- Geosynthetic capping system.

A detail description and advantages/disadvantages of these two capping approaches are provided in the sections below.

2 EARTHEN CAPPING SYSTEM

Since introduction of the first national regulations in the US, which introduced binding requirements for landfill capping, the core elements of the sealing systems, were earthen components such as clay as the classic sealing layer and gravel / sand as the drainage layer for water / leachate and gas.

These guidelines were followed by most countries and have been known as ‘Traditional’ solution for landfill capping. The earthen components shall be compliant with the installation criteria and constructed to a high standard, which generally include material suitability testing, as well as compaction control testing.

The long-term effectiveness of the traditional landfill capping systems are often susceptible to factors such as:

- Desiccation cracking;
- Erosion;
- Differential settlement;
- Displacements;
- Material availability;
- Interface shear strength; and
- Construction quality control.

These factors are described in the following sections.

2.1 *Desiccation cracking:*

Desiccation cracking refers to formation of cracks in near surface zone of the clay layer as a result of reduction in soil water content. This results in significant increase in permeability of the landfill clay liner. Consequently, the risk of release of landfill leachate or landfill gas will increase. It also increases the risk of infiltration of stormwater into the waste material and the potential for higher rate of leachate generation.

2.2 *Erosion:*

Erosion predominantly refers to soil loss at the near surface zone of the clay layer due to surface water runoff particularly following major rain events. This results in reduction of effective thickness of the clay liner; hence significant loss of integrity of the landfill capping system.

2.3 *Differential settlement:*

Differential settlement is primarily due to the fact that the landfill cap is constructed above various types of compressible waste with various settlement behaviors.

2.4 *Displacements:*

Displacements in the capping system mainly occurs on the capping slopes due to the lateral loading acting on the earthen components of the capping system. These displacements can be more significant when the degree of soil saturation changes (predominantly relevant to climatic effects) within the body of the earthen capping system.

2.5 *Material availability,*

Availability of suitable earthen material to construct the capping system is an important factor to estimate the cost of construction. Where suitable earthen material is not available in relatively close proximity to the landfill site, the construction cost will dramatically increase due to higher cost of haulage of suitable material from a borrow area.

2.6 *Interface shear strength, and*

Interface shear strength between different layers of earthen material used within the capping profile is a significant parameter for stability of the earthen capping system. This can be also dependent on degree of saturation of each of the earthen components, seismic behavior of each of the layers which will affect the geotechnical properties of the soil components of the landfill capping system.

2.7 *Construction quality control.*

Construction quality of each of the earthen components of the landfill capping system has a direct effect on the integrity of the entire capping profile. This quality control normally involves material suitability and compaction testing. Inadequate quality control on the construction of the earthen capping layer results in poor construction and loos of integrity of the landfill capping system.

3 GEOSYNTHETIC CAPPING SYSTEM

To overcome some of the issues as detailed in section 1, various geosynthetic materials have been developed and utilised in landfill sealing and drainage systems, commonly known as 'Geosynthetic' capping solutions.

In a 'geosynthetic' capping system, geosynthetic clay liners (GCLs) and geomembranes are commonly geosynthetic material that are used in landfill capping profile in order to fulfil the 'barrier' function of the capping system. Geonets and geocomposite drains are utilized for fulfilling the 'drainage' function of the capping system.

3.1 *Generic geosynthetic capping profile*

A generic landfill capping profile for a 'geosynthetic' solution includes the following components from bottom to top:

- Leveling layer: this is normally a layer of soil that is placed on top of the waste material or over the intermediate soil cover. This layer creates a uniform surface that underlays the rest of the capping layers.
- Geonet or geocomposite drainage layer: this layer forms a drainage layer for collection and release (or use) of landfill gas which is generated from the waste material post-decommissioning of the landfill. Landfill gas pipes and other relevant equipment will be connected to this collection system.
- Geosynthetic clay liners (GCLs) and/or geomembranes: this layer creates the contamination barrier for the landfill capping system. The geomembrane component can be selected from a variety of available geomembrane products depending on the site-specific performance requirements and life expectance for the capping system.
- A second layer of geonet or geocomposite drainage layer: this layer forms a drainage layer for the stormwater runoff that infiltrates into the earthen components of the capping system. The final capped landform shall be designed such that the stormwater gets collected and directed to the designated discharge locations around the toe of the final landform.
- Vegetation support layer: this layer is constructed as part of the landfill capping profile in order to promote / support revegetation of the final landform. It normally includes a layer of sub-soil overlain by a layer of topsoil with vegetation that develops over the surface of the final capped landform.

A generic geosynthetic capping profile is shown on Figure 1.

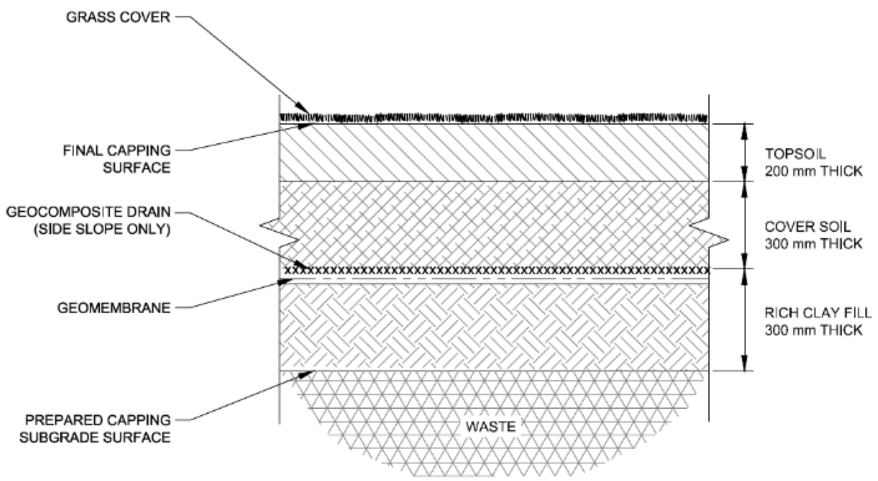

Figure 1. Generic landfill geosynthetic capping profile.

3.2 *Composite barrier*

With regards to the ‘contamination barrier’ component of a landfill capping profile, ‘Composite’ barriers which are usually a combination of a geomembrane as the primary liner and a GCL as secondary liner are commonly used in landfill capping profile.

Generally, the preferred geomembrane material is a ‘linear low density polyethylene (LLDPE)’ in order to better accommodate the strains associated with differential settlements within the waste body of the landfill.

Geogrids are commonly utilized for the purpose of minimizing the risk of interface failure of the liner. Geomembranes with textured surfaces are utilized to enhance shear strength parameters at the interface between the geomembrane and the layers above and below the membrane.

4 MULTI-CRITERIA ASSESSMENT OF LANDFILL CAPPING

4.1 *Multi-criteria assessment (MCA)*

Multi-criteria assessment (MCA) is a decision-making tool used to evaluate problems when one is faced with a number of different alternatives and expectations and wants to find the best solutions with regard to different and often conflicting objectives. The ability of MCA to deal with complex and unstructured decision problems in the sphere of environmental and natural resource management, which involve a number of conflicting technical, ecological, environmental, social and economic objectives, multiple interests groups and different languages of valuation is widely acknowledged.

MCA constitutes both a framework for structuring decision problems, as well as a set of methods to generate preferences among alternatives. MCA has the potential to take into account conflicting, multi-dimensional, incommensurable and uncertain effects of decisions explicitly enabling it to focus more on the – decision process itself, and not on a final result.

A multi-criteria problem is characterized by the presence of a finite set of alternatives (in this instance alternative capping profile for a landfill capping system) and the existence of different (and often conflicting) evaluation criteria under which we evaluate each alternative. The MCA problem may then be represented in the form of a matrix (alternatives vs. criteria) depicting the evaluation of each alternative regarding to each criterion.

Supposing that it is possible to evaluate each alternative in relation to each criterion, we can obtain a weak ordering of the alternatives for each criterion, ranging from best to worst. The multi-criteria decision problem consists of ranking the alternatives according to an ordering that is a legitimate synthesis of the criteria.

4.2 *Developing MCA for landfill capping*

A multi-criteria assessment matrix was developed for the purpose of assessing various alternatives for landfill capping. This matrix can be filled in based on the site-specific information and the outcome from multi-criteria assessment will demonstrate which alternative will perform best in relation to the criteria set for the purpose of this assessment.

4.2.1 *Alternatives*

The alternatives which are normally considered for a landfill capping profile are all including the following layers:

- Leveling soil layer on top of the waste material or over the intermediate soil cover.
- Geonet or geocomposite drainage layer for collection and release (or use) of landfill gas.
- Geosynthetic clay liners (GCLs) and/or geomembranes forming the contamination barrier.
- A second layer of geonet or geocomposite drainage layer for the stormwater runoff that infiltrates into the capping system.
- Vegetation support layer.

The main item which commonly requires to be assessed using multi-criteria assessment approach, is the ‘contamination barrier’ component of the capping profile. Some example alternatives for this item are listed as follows:

- Compacted clay liner (CCL);
- Geosynthetic clay liner (GCL);
- Coated GCL;

- Linear low density poly ethylene (LLDPE);
- Bituminous geomembrane.

4.2.2 *Criteria*

Various criteria can be assigned for the purpose of a multi-criteria assessment for a capping system. Some example criteria are listed as follows:

- Technical criteria:
  - Technical suitability for site-specific requirements,
  - After-use conditions,
  - Geotechnical stability,
  - Ability to execute and establish quickly,
  - Operational activities and developments,
  - Robust technology for post-closure period.
- Environmental criteria:
  - Satisfying relevant environmental authorities requirements,
  - Ability to minimise leachate generation,
  - Ability to minimise landfill gas impacts,
  - Ability to withstand strong differential settlement.
- Economic criteria:
  - Initial capital cost,
  - Vegetation maintenance,
  - Erosion repairs,
  - Cap perforations for landfill gas,
  - Dependence on imported earth fill for construction.

4.2.3 *Weighting*

As part of the multi-criteria analysis, a weighting (as percentage) is assigned to each criterion with the total weighting being 100%.

4.2.4 *Ranking*

For the purpose of the multi-criteria analysis, ranking of the alternatives is undertaken corresponding to each of the defined alternatives. A product of ranking and weighting for each item in the multi-criteria matrix is calculated and reported as the total score for that particular alternative.

4.2.5 *Discussing results*

An overall ranking based on the total score for each alternative capping profile is calculated and reported. A discussion will need to be undertaken at this point in order to gauge the relevance of the outcomes from the multi-criteria analysis and to agree on a final preferred alternative for the capping profile.

5 CONCLUSION

Generally for a landfill capping system, there is no solution optimizing all criteria at the same time and compromises have to be found. As various dimensions are taken into account, the main goal is to find a balance between them, aiming at ‘compromise solutions’ which colloquially could be called ‘the least bad’ solutions, to emphasize that we are far away from naively aiming at the ‘best’ solutions as in cost-benefit analysis. A wide set of multi-criteria methods have been developed for this purpose. These methods have particular features regarding information requirements, criteria assessment, modelling of preferences and decision rules.

Multi-criteria methods may provide a powerful framework for policy analysis in the context of sustainability problems, since they can accomplish the goals of being inter- or multi-disciplinary (accounting for the multiple dimensions present), participatory (open to all stakeholders), and transparent. Stakeholder participation may be included in the overall structure of the MCA process: alternatives and criteria generation, weighting and evaluation of alternatives and discussion of results.

REFERENCES

Munda, G. 2008. Social Multi-Criteria Evaluation for a Sustainable Economy, Berlin Heidelberg: Springer-Verlag.
Munda, G. 1995. Multi-criteria evaluation in a fuzzy environment. Theory and applications in ecological economics, Physica-Verlag, Heidelberg.
Antunes, P., Santos, R., Videira, N., 2006. Participatory decision making for sustainable development – the use of mediated modeling techniques, Land Use Policy, 23, 44-52.