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Use of geosynthetics for lining and drainage systems in quarry landfills

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ABSTRACT: The use of old quarries for waste disposal is becoming increasingly popular due to their large void space and therefore potentially large storage capacity for waste. Furthermore, this practice can lead to a reasonable restoration of what might otherwise be scars on the landscape. As with other solid waste landfills, old quarries need to be designed on a fully contained basis to prevent migration of leachate and landfill gas. The major technical challenge that needs to be overcome to construct this type of landfill is developing an appropriate and robust lining and drainage system for the steep sided quarry walls and the base. This paper discusses some design issues for lining and drainage systems for quarried landfills based on experiences in Australia and Hong Kong.

1 INTRODUCTION

Old quarries, especially those formerly used to mine sand and gravel, are increasingly used as waste containment facilities, even though these are usually important sources of groundwater recharge. Nowadays, most of these facilities must meet stringent environmental requirements, usually leading to the use of geosynthetics (geomembranes, GCLs, geocomposites, geotextiles) in the containment systems and cover systems (Bouazza et al., 2002) to ensure that migration of leachate and landfill gas is minimised and that current legal requirements for non pollution are met.

The engineering challenges in designing such containment facilities for an old quarry include developing an appropriate lining and drainage system for the steep sided walls and the base, while at the same time maximising void space. There are also issues associated with the practical construction of these lining and drainage layers.

Quarry landfills are usually deep and steep sided. Old quarries 50 metres deep or more are being converted into solid waste landfills. The large depths of waste generate high stresses on the basal lining and drainage system. The steep, often vertical, side slopes present practical challenges to designing a stable lining system that will not develop integrity failures during waste loading.

Issues that need to be considered during design and construction include:

- Effect of high stresses on the lining and drainage system
- Adequacy of the drainage system
- Stability of the liner and drainage system on steep slopes
- Methods of ensuring liner integrity during waste settlement and down drag

2 EFFECT OF HIGH STRESSES ON LINING AND DRAINAGE SYSTEM

High stresses imposed on the liner system can lead to deformations of the geomembrane from interaction with granular drainage material. They can also lead to reduced flow performance of geocomposite drains.

2.1 *Geotextile Protection of Liner*

Geomembrane damage from granular drainage layers can be avoided by using protective layers of geotextile cushions.

Deformation testing is used to examine the integrity of the protected geomembrane and to better understand the interactions of the various interfaces in the liner system. Deformation testing is carried out in a large scale geostatic test rig (Figure 1) using the various combinations of geosynthetics and granular layers that are under consideration at different stages in the design development.

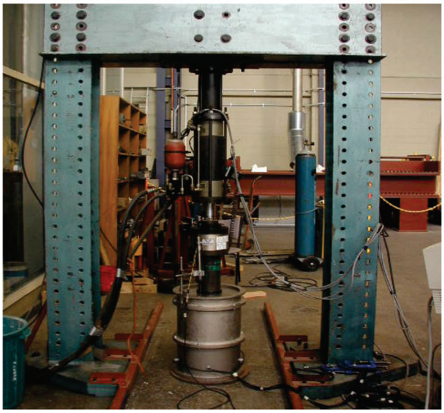

Figure 1. Deformation testing.

The layers of granular and geosynthetic materials are placed into a cylindrical vessel and subjected to appropriate loadings, with submergence to achieve hydration as required. Deformation is measured by use of a highly deformable thin zinc plate which is placed under the geomembrane and retains the deformed shape on disassembly.

This is a performance test carried out at the design stage. Other geotextile parameters such as unit mass, thickness and CBR burst strength can subsequently be used for quality control purposes, although none of these index parameters are entirely satisfactory as they do not measure manufacturing variations in needling and fibre interaction. A correlation with the pyramid cone puncture test would enable better manufacturing quality control.

2.2 *Compression of Geocomposite Drains*

As the depth of old quarries being used for waste disposal increases to 50 m or more, then more careful assessments need to be made of the capacity of geocomposite drainage layers under these loads. An example is presented in the next section.

3 ADEQUACY OF DRAINAGE SYSTEM

3.1 *Estimate of Drainage Flow Quantities*

Estimation of leachate flows is critical to the subsequent evaluation of the required drain performance as well as leakage rates and leakage drain requirements in double lined systems. This evaluation needs to take into account rainfall and evaporation rates, waste and soil cover permeability, and the efficiency of stormwater drainage systems that are used to divert stormwater from the waste body.

The HELP model developed by the US EPA is commonly used, although it is widely recognised that some sort of correlation with real local data is preferred.

3.2 *Reduction Factors for Geocomposite Drains*

During the design of a new landfill on the north-west side of Sydney, it was decided to investigate whether a geocomposite drainage layer could be used instead of gravel for the leachate drainage layer.

This landfill is being constructed in an old breccia quarry excavation, and the depth of backfilled waste is intended to be 50 m. The landfill is replacing a nearby landfill, where measurements have shown that the waste was placed with a unit weight of 1.8 tonnes/m^3. The required design pressure on the geocomposite drain was therefore taken as 1,000 kPa.

The design pressure gave rise to questions of whether the geonet drainage core would compress under this load, leading to inadequate flow capacity, and whether the geotextile filters would intrude into the core and block flow. In addition, the Environmental Protection Authority (EPA) required consideration to be given to clogging of the drainage layer by the leachate.

These issues were evaluated using the methods put forward by Giroud et al (2000a and 2000b), in which equivalent transmissivity of different materials is shown to not provide equal drainage performance.

3.2.1 *Laboratory Testing*

The EPA regulations require a drainage layer to comprise gravel, or a combination of gravel and geonet. An acceptable design could comprise a gravel layer 300 mm thick with a coefficient of permeability, k, greater than 1×10^{-3} m/s.

Extensive laboratory testing was carried out to determine whether the tri-planar geocomposite drainage layer would be equivalent to this gravel drainage layer, and whether the drain would clog.

Flow rate (transmissivity) testing of the geocomposite was carried out with cover soil on each side, to establish flow reduction due to intrusion of the geotextile under different hydraulic gradients and increments of applied load up to 1,000 kPa.

Cover soil and geotextile combined permeameter testing was carried out, to determine clogging potential, under a load of 1,000 kPa. Compressive creep testing was available with a long term constant compressive load.

3.2.2 *Clogging*

Clogging occurs when fine material flows through the drainage system and blocks small pore spaces, or when chemical precipitation or biological growth occurs within the pore spaces. A poorly designed gravel leachate drainage layer will be just as susceptible to clogging as a poorly designed geosynthetic drainage layer.

Clogging is related to the flow through the critical component of the system, the void size, the temperature in the collection system, the leachate chemistry (especially BOD, TSS, COD and Ca) and the saturation or dryness of the system. Some types of waste will generate leachate that will initiate clogging more than others. In addition, the void size can be reduced by the high compressive forces generated by large depths of waste.

3.2.3 *Reduction factors*

Values of design reduction factors, as proposed by Koerner (2005), were determined from the test results. These reduction factors were determined for soil clogging, intrusion, creep, and chemical and biological clogging of the geotextile filter as described in Cowland and Sadlier (2004) and set out below.

Soil Clogging: 1.0 (good performance test data)
Creep Reduction: 2.0 (little data)
Intrusion into Voids: 1.0 (good data)
Chemical Clogging: 1.2 (weak leachate)
Biological Clogging: 5.0 (good data)

Reduction Factors for intrusion, creep, and chemical and biological clogging of the geonet drainage core were determined as set out below.

Intrusion: 1.0 (good performance test data)
Creep: 1.9 (extensive creep test data)
Chemical Clogging: 1.5 (weak leachate)
Biological Clogging: 1.5. (weak leachate)

3.2.4 *Results*

It was demonstrated that a geocomposite containing a tri-planar geonet would have equivalent or better performance under the site conditions than a gravel layer prescribed by regulatory guidance. The geonet drainage flow capacity was found to have a factor of safety of 10, and the geotextile filter flow capacity was found to have a factor of safety greater than 7.

4 STABILITY OF LINER SYSTEM

Hong Kong has a terrain which is characterised by steeply sloping valleys. In order to increase capacity before landfilling, and to provide daily cover material, soil and rock is quarried from the valley sides. Therefore, a large proportion of the total area of the lining and drainage systems needs to be placed on steep soil slopes and near vertical rock slopes (Figure 2).

As the majority of the surfaces to be lined were sloping, a strong emphasis was placed on providing effective drainage systems. It was recognised that the drainage of leachate to a suitable treatment location, utilising the sloping ground, was just as important as leachate containment.

Figure 2. Quarry landfill.

A typical Hong Kong landfill liner for base areas, and slopes up to 45°, comprises a geomembrane overlying a geosynthetic clay liner (GCL). For slopes steeper than 45° a single geomembrane liner is permitted. Due to the difficulties of placing GCLs on very steep slopes, it was decided that a single geomembrane liner could be used in this situation as long as careful attention was paid to the design of the groundwater and leachate drainage layers.

A groundwater drainage layer is usually placed below the liner, and a leachate drainage layer is placed above. Depending on various design and availability considerations, these drainage layers may comprise crushed granitic rocks (with a geotextile cushion to protect the liner) or geonets. A typical arrangement is shown in Figure 3.

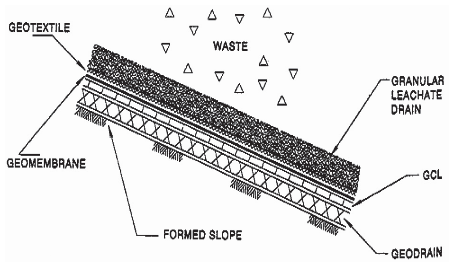

Figure 3. Typical Hong Kong liner system.

It is planned to place 120 to 140 metres depth of waste in these landfills, and with a unit weight of 1.4 tonnes/m^3 this will exert a pressure of nearly 2 MPa on parts of the landfill lining and drainage systems.

4.1 *Liner Interface and Internal Shear Strengths*

These landfills have required extensive laboratory testing, using the actual materials proposed for each part of the landfills, to determine the interface shear strength between the various layers and the internal shear strength of the geosynthetic clay liners under high loads (Sadlier et al, 1998).

It was also necessary to consider whether peak or residual strengths should be used for design. Based on limited knowledge of landfill failures it would be unwise for the designer to rely on peak strength throughout the lining system. From a finite element back analysis of the Kettleman Hills Landfill failure (Byrne, 1994) it had been found that the onset of progressive failure mobilises residual strengths on the side slopes, although the peak strength may still be relied upon for a proportion of the base liner.

The peak shear strength of a reinforced GCL is represented by the strength of the internal fibres and their bonds. Once these fibrous bonds are broken then their internal shear strength is significantly reduced.

The analysis of side slope liner stability is complicated for a multi-layered liner and leachate collection system (Fowmes et al, 2006). The unit load of the waste gravitationally induces shear stress through the leachate collection system onto the liner and then onto the groundwater collection system. Depending on the frictional characteristics of the surfaces involved, it is possible that only a portion of the induced shear stress is transmitted to the layer below. A smooth upper surface is often selected for the geomembrane to create a low strength interface to keep shear forces from the liner system.

With a low strength or low shear strength lining material being placed on steep slopes (interface friction angles can be as low as 7°), it would appear that there is a high risk of a localised slip occurring. However, many of the local and temporary stability problems associated with these materials can be avoided by utilising an incremental balanced method of placing the overlying load with a corresponding toe buttress as outlined by Giroud and Beech (1989). This recognises that a sliding failure can be prevented by provision of adequate horizontal shear strength near the toe of the slope and these methods have been used successfully in Hong Kong.

5 SYSTEM INTEGRITY

Construction and quality control of complex multilayer liner systems on steep slopes with potentially high waste loads requires the highest standards of engineering supervision. Apparently small variations in the works and their execution can have very significant consequences and any problems may be very difficult to access for later rectification.

Under these circumstances there is no substitute for knowledgeable and experienced engineering supervision with adequate authority to ensure compliance.

6 CONCLUSIONS

Case histories of leachate containment and drainage have been presented for quarried landfills in Australia and Hong Kong.

It has been shown that, with careful attention to engineering detail, extensive site specific testing of materials and performance, and a well developed understanding of the different mechanisms and the relationships between them, the challenges associated with quarry landfills can be successfully overcome.

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