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Case Studies: The Design And Construction Elements That Arise When Hazardous Waste Lagoons Incorporate Steep Sideslopes.

C. Cilliers. Jones & Wagener, Johannesburg, South Africa. cilliers@jaws.co.za
J. Msiza. Jones & Wagener, Johannesburg, South Africa. jabulile@jaws.co.za

ABSTRACT

In an attempt to maximise the storage capacity of hazardous waste lagoons within the permitted boundaries, the sideslopes of such facilities are increasingly built at steeper gradients. The placement of compacted clay liners (CCL's) becomes impractical at such gradients thereby promoting the sole use of geosynthetic materials. The ion exchange debate has increased the awareness of possible problems that may arise, in addition to desiccation and seam separation, in the use of geosynthetic clay liners (GCL's). The focus of this paper will be on designing lagoon impoundments which have steep sideslopes yet incorporate practical liner systems. Two case studies will be presented; a waste disposal facility in Kwa-Zulu Natal and a landfill site in Gauteng. Lessons learnt in terms of design and construction are presented.

1. INTRODUCTION

When the boundaries of hazardous waste lagoons restrain the storage capacity of such facilities, often an option to increase the storage volume is by steepening the sideslopes. During the design stage, the construction difficulties of steeper slopes may receive less consideration than achieving the required storage capacity.

As slopes are steepened greater than 1(vertical):3(horizontal), it is no longer practical to use conventional compacted clay liners (CCLs).

Alternative lining systems incorporating a wide range of geosynthetics often supply a solution to cases where conventional methods become impractical. If the slope is steepened to the extent that a CCL is completely impractical, the design may have to consist solely of geosynthetics.

The application of a geosynthetic clay liner (GCL) may seem suitable to steep sideslopes. However, due to seem separation of GCLs occurring beneath exposed geomembranes, a ballast layer on the sideslopes will be required. Designing a ballast layer is possible but it is likely to further complicate the liner installation.

There has been extensive research into the compatibility of GCLs with aggressive leachates and the suitability of bentonite types with calcium rich subgrades and cover soils. If the compatibility of a GCL and the waste product is questionable, what other geosynthetic alternatives are there?

This paper discusses the design and construction elements of one such alternative: The use of a triple geomembrane layer with geosynthetic drainage cores acting as detection systems between layers.

This alternative was used on two sites: the third phase of a slurry disposal facility (Site A) in Kwa-Zulu Natal and a new leachate dam at a landfill site (Site B) in Gauteng.

2. SITE A

The site is surrounded by a railway loop that forms the northern, southern and eastern boundary (refer to Figure 1). Powerlines are also located on these boundaries, their servitudes overlapping the edges of the site. There are two phases constructed within the facility with Phase 2 forming the western boundary for Phase 3.

Figure 1. Plan view of Phase 3 of the slurry disposal facility at Site A in Kwa-Zulu Natal

The railway loop prevents a fourth phase from being added to the facility. The external toe of the embankment of Phase 3 was extended to be parallel within the railway embankment leaving only the width required for the storm water trench and access road in between. This allowed the remaining area within the loop to be used for Phase 3.

During the geotechnical investigation, it was established that the site was mainly underlain by residual siltstone. However, the southern area of the site was underlain by hard rock (residual sandstone) at a depth of 2.3 m. Therefore, an allocation for hard-rock excavation would be required if the design called for a deeper basin. (The final design's deepest point is 4m below ground level, limiting the hard-rock excavation to 2m).

Table 1 summarizes the results of an investigation which calculated the additional volume capacity gained by steepening the sideslopes.

Table 1. Comparison of volume gained by steepening the sideslopes

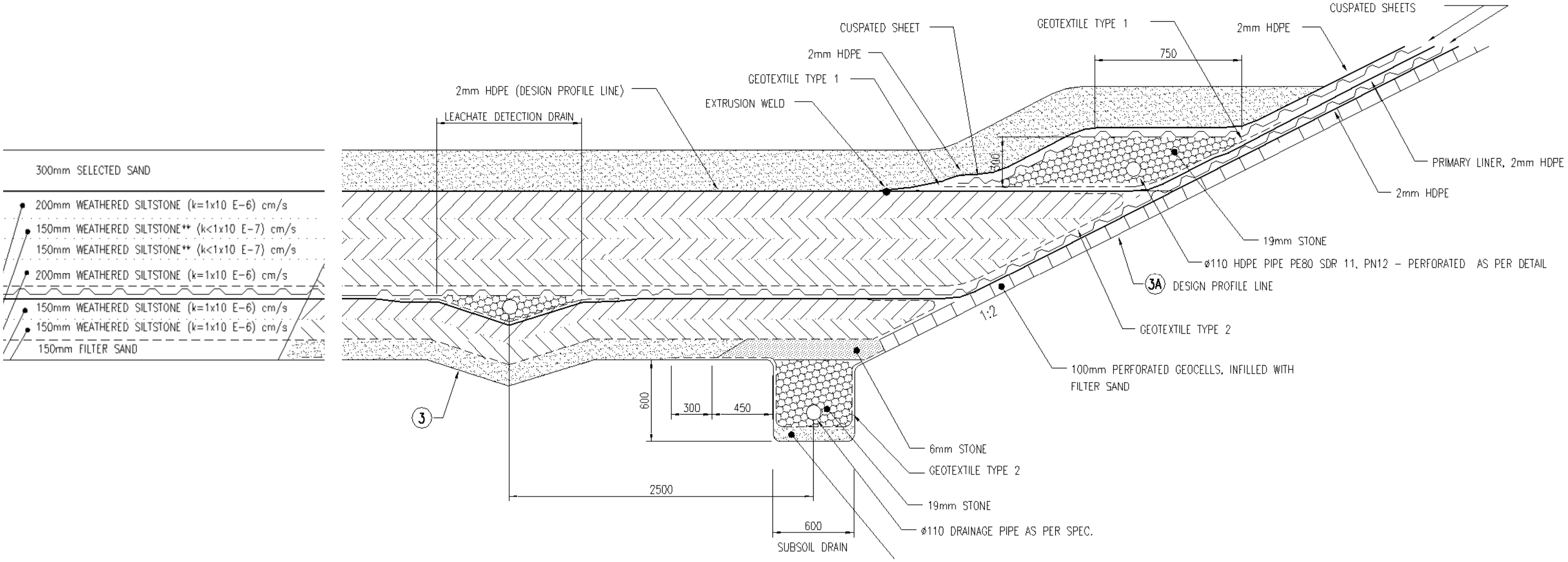
Slope:	Volume (m^3):	Difference (m^3):	% Difference:
1:3	425 044		
1:2	448 449	23 405	5.5 %

By steepening the sideslopes the client gained an additional 5.5%. This comparison led to the final design incorporating 1:2 sideslopes. The consequences of this decision are described later in this paper.

2.1 Liner design

The constituents of the basal liner system are listed below followed by a discussion on the alternative liner design used on the sideslope. The liner system is shown in Figure 2:

- Subsoil drainage layer: This layer consists of filter sand specifically graded to prevent in-situ material from clogging the drainage layer. A network of HDPE pipes, enclosed by 6mm and 19mm stone, transport subsoil water to the confluence at the lowest point of the dam. At this point, the water is collected within an HDPE barrel sump. The sump is either drained by a gravitational outlet pipe, which leads to a manhole positioned externally from the dam, or a submersible pump lowered down a riser pipe from the crest.



** Weathered siltstone blended with bentonite

Figure 2 Typical liner detail

- Secondary composite liner: This liner consists of two layers of compacted in-situ material in intimate contact with a 2.00mm HDPE geomembrane.

- Leakage detection layer: This layer consists of a cuspated sheet in the basin and the sideslopes. The layer is drained by a network of HDPE pipes which are enclosed in 19mm stone. The confluence of the network is also at the lowest point of the basin where any leakage water will be contained in another barrel sump. The sump is emptied by a submersible pump lowered down a riser pipe from the crest.

- Primary composite liner: This liner consists of 2 compacted in-situ layers and 2 compacted in-situ / bentonite blended layers (indicated with ** in Figure 2) in intimate contact with a 2.00mm HDPE geomembrane.

- Leachate collection drainage layer: This layer consists of a layer of selected sand above the primary composite liner in the basin. The selected sand is specifically graded to filter the waste product and aid in de-watering the phase during operation. The layer is drained by a collector pipe that is located along the toe of the southern wall. The collector pipe drains to a barrel sump positioned in close proximity to the two previous sumps. The sump is drained via a submersible pump that is lowered down a riser pipe from the crest.

- Sideslope leakage detection layer: Due to the steepness of the internal slope, a second cuspated sheet and a third 2.00mm HDPE geomembrane are added to the sideslopes. These become the primary drainage core and primary liner on the side slopes respectively. The primary drainage layer is drained by a collector pipe that is located along the toe of the internal wall. The collector pipe drains to a barrel sump positioned in the low point of the dam. Leakage water is pumped up to the crest through a riser pipe using a submersible pump.

As constructing a CCL on the steep sideslopes would clearly be impractical, an alternative to using GCLs was given careful consideration. If GCLs were to be used, the liner system would require adequate confinement in the form of a ballast layer in order to prevent seam separation (R.M. Koerner & G.R. Koerner, 2005). The design of the ballast layer would most likely include geocells filled with stabilised material. Installing the geocells without the use of pegs may have been a difficult process.

It was during this design stage that the awareness of the compatibility of GCLs with aggressive leachates with high concentrations of polyvalent cations was raised. A paper by Johns (2007) stated that the results of a swell index test could be used to make tentative predictions of the long-term performance of the GCL by consulting the body of research and literature correlating the swell index of bentonites to long-term hydraulic conductivities in GCLs. His test results indicated that depending on the leachate, the free swell of the bentonite can be reduced by a factor of 5 which correlates to an increase in hydraulic conductivity of four to five orders of magnitude.

The swell index test is described in the ASTM D5890 – 95 specification and involves the evaluation of the swelling properties of a clay product. Two grams of clay are incrementally and periodically added to a beaker containing 100ml of reagent water (or leachate) until the entire two grams has been added. The solution is left to stand for a period of 16 hours after which the amount of swell of the clay is measured in ml/2g. The sample is required to swell to 24ml/2g in order to meet the GRI-GCL specification.

After carrying out the swell index test with the slurry from Site A, the bentonite reached 25% of the swell required to achieve the desired permeability. This indicated that the application of GCLs to this specific project was not suitable.

It was decided that the liner system on the sideslope would not contain composite liners. Instead, the system would rely on the extremely low permeability of the geomembrane layers and the steepness of the sideslope. As a precaution, another drainage layer and geomembrane were added to the sideslope.

If the primary liner was damaged, the primary drainage layer would act as a break and prevent pressure build-up on the secondary liner. As the sideslopes would be very steep, the leachate entering the drainage layer would drain down the slope faster than if flatter slopes were used. If the leachate did leak through the primary and secondary liner, it would be drained by the secondary drainage layer which would prevent pressure build-up on the tertiary geomembrane.

A challenge in the design was the interface of the triple liner with the conventional liner system used in the basin (refer to Figure 2):

- It was decided that the secondary drainage layer on the sideslope would connect to the basin leakage detection layer, leaving the four clay layers to end at a point.

- The primary drainage layer on the sideslope would end and be drained by a pipe network at the toe. The primary liner would be extrusion-welded onto the primary liner on the basin.

This triple liner design applied to steep sideslopes was submitted to and approved by the Department of Water and Forestry Affairs (DWAF).

2.2 Construction

The difficulties encountered during the construction of the facility are discussed below. Challenges were mostly experienced during the shaping of the internal sideslopes and the placement of material on them.

2.2.1 Earthen embankments

The earthen embankments were constructed using conventional cut to fill methods. More cut was required than fill and material was stockpiled north of the site. The steepness of the sideslopes did not affect the layer works. Once the layer works were complete, an excavator was used to roughly shape the walls. The steepness of the sideslopes led to significant erosion of the slopes after rainfalls. The rainwater left large gullies in the sidewalls which may have been less excessive if the slopes were flatter. The gullies were prevented from worsening by filling them with filter sand. As the sand is graded to filter soil particles in the liquid, further erosion within the gullies was prevented.

The rough sideslope surface then required finishing to a level smooth enough to place geomembrane onto it. Due to the steepness of the slope, the final trimming of the slope could not be carried out effectively by hand labour. The solution to the challenge was to drag a heavy 400mm I-beam along the slope. The I-beam was connected to a tractor on either side with a chain. One tractor drove along the crest of the wall and the other tractor drove along the toe of the wall and together dragged the beam behind. Due to the weight of the beam, imperfections were removed resulting in a windrow of loose material at the toe of the wall. Once the finish was completed, the geocells were installed on the wall.

The geocells on the sideslopes were included in the design to stabilise the filter sand on the wall. These were installed by bracing the four corners of the geocell panel into the wall with steel rods. Each cell along the side of the panel was anchored using 2.00 mm wire bent into a u-shape and hammered into the slope. Once the sides were completely anchored, the steel rods in the corners were removed.

Placing filter sand into the geocells from both the bottom and the top was considered. It was agreed that if the geocells were filled from the top downwards, the geocells would sag due to a filled cell above not being supported by a filled cell below. Therefore it was decided to place the filter sand starting from the bottom and filling upwards. The difficulty was the placement of material on the higher reaches of the sideslope. This was solved by attaching a supported conveyor onto a trailer. The conveyor transported material to the end of its reach where it was deposited high onto the sideslope. Once deposited, a team of labourers spread the filter sand into the geocells, moving from the lower cells upwards.

Once the filter sand was placed in the geocells, excessive erosion occurred after heavy rains. Filter sand was washed out of the geocells as the water ran down the slope. This erosion was repaired each time after it had rained and the process only ended once the first geomembrane layer was installed on the sideslope.

The final challenge faced before the installation of the liner was the casting of the overflow pipe supports. These were placed at a depth of 800mm from the crest. Each support required a set of 23 cast-in stainless steel bolts which supported a stainless steel frame used for the geomembrane penetrations. The excavation for each support was hand excavated on the side of the slope. It was difficult to excavate the compacted layers while standing on the steeper slope which resulted in the process taking longer than planned. The concrete was mixed at the crest, lowered down a chute to the excavation and cast in-situ. The bolts cast in the concrete were required to be accurately placed so that the stainless steel frame would fit onto the support. The accuracy was difficult to achieve working on the steeper slopes.

The steepness of the sideslopes resulted in the access ramp into the basin being steep. As the progression of the basin preparation ensued the ramp was continuously made steeper. It reached a stage that one could not see the ramp before driving onto it or when driving up the ramp could not see an approaching vehicle. This was clearly a safety hazard and the contractor placed a traffic controller at the top of the ramp to direct traffic.

2.2.2 Liner installation

The steep sideslopes presented general difficulty in deploying the liner and welding it on the sideslopes. Once the geomembranes were placed it was difficult to manoeuvre the sheets to achieve the required overlap for a wedge weld.

The function of the anchor trench was clearly illustrated during installation. As the steepness of the slope increases, the component of the weight of the geomembrane parallel to the slope increases. This tends to drag the geomembrane down the slope and larger anchor trenches are required. During the installation stage the anchor trench was re-opened to install cables. The result was the sheets tended to sag down the slope resisted only by the small amount of friction between the geomembrane layers. Before the anchor trenches were backfilled the geomembrane had to be pulled up the slope again.

As the liner installation was nearing completion, the sumps and riser pipes were installed. There were four riser pipes, each connected to one of the four collection sumps. The subsoil riser pipe was relatively easy to install because it was supported within the embankment, compared to the other three which required cement stabilisation. The difficulties included transporting the stabilised material up the slope while working on rope ladders. All this activity was taking place above the installed geomembrane exposing it to risk of damage by spade or other tool. Eventually the placement of the material reached a stage that it became too difficult to transport the material up the slope and instead the material was transported downwards from the crest by means of a chute.

Due to the overall thickness of the triple geomembrane system on the sideslope, great precaution was taken while removing the access ramp from the sideslope. It is likely that had damage occurred it may have extended to the lower layers of the liner system, especially if the damage had been caused by machinery.

After the access road was removed the rope ladders became one of the only ways to access the dam. The other was to walk down the north western corner, which was less steep than the walls but still difficult to descend. This restricted access into the basin for people who could neither use the rope ladder nor manage to walk down the corner.

3. SITE B

The new leachate dam (Cell 7) is bordered on the south by an existing leachate dam (Cell 5) and an existing landfill cell (Cell 6), see Figure 3 showing the site layout. Future cells will be developed on the western and northern sides of Cell 7 within the permitted boundary as the landfill progresses.

Figure 3. Plan view of Cell 7 of the landfill site at Site B in Gauteng.

The original development plan of the landfill site comprised of one cell basin north of Cells 5 and 6. The site life and storage volumes were calculated according to this development plan. A leachate storage dam was required and so this implied that the design had to be amended to split the northern cell into a lagoon and landfill cells. This could be accomplished by constructing earthen division walls but the volume taken up by these results in a loss of waste filling volume. As leachate is treated, storage capacity requirements of Cell 7 decrease. Eventually, Cell 7 will become the final landfill cell. Therefore, provisions for its future conversion from a lagoon into a landfill cell were incorporated into the current design.

The following conceptual design objectives led to a total of 12 different options for consideration:

- Investigate different side slopes for the embankment to minimise the fill required for its construction.
- The elevation of the embankment was to be limited to that of adjacent Cell 5. This ensured that continuous lining was possible between Cell 5 and Cell 7 resulting in no area being left unlined.
- The cut to fill was to be as balanced as possible.
- The client requested that four different storage capacities (including freeboard volume) be investigated and their costs estimated.
- Three different internal wall slopes were also investigated with consideration of the liner stability on the slopes.

After consideration of the concepts, the option decided upon incorporated 1:2 internal sideslopes.

3.1 Liner Design

The lining system of Cell 7 is similar to that of Phase 3 at Site A except for the following:

- The outlet pipes of the subsoil water drainage, leak detection and future leachate collection systems, led via gravity draining pipes from the barrel sump of each system to a large reinforced concrete sump. The concrete sump was internally lined, with three compartments for the three different collection systems. A riser pipe was also connected to each barrel sump to provide the option of pumping up the sideslope to a pump station located at the crest.

- The Site B Landfill site is underlain by weathered sandstone and siltstone which meet the specification for use in a CCL. As there was an abundant source of clayey material, bentonite blending was not required and the use of a GCL liner (in the basal liner system) was not considered.

- Unlike Phase 3 at Site A, where the sideslope lining systems consisted of three 2.00mm geomembranes with drainage cores in between, Cell 7's lining systems consisted of a primary liner of 2.00mm, a secondary liner of 1.50mm and tertiary liner of 1.00mm. Drainage cores were located both between the 2.00mm and 1.50mm and the 1.50mm and 1.00mm geomembranes.

- A 300mm thick layer of cement stabilised selected sand was included as the final layer for protection of the primary liner. The layer will also ensure that there is a distinct separation between the liner and sludge to prevent damage when the cell is de-sludged for the construction of the leachate collection system. At Phase 3 at Site A, loose selected sand was used as ballast.

3.2 Construction of Cell 7

The construction of Cell 7 commenced in August 2007 with anticipated completion in a year. One of the major challenges faced was above-average rainfall in the months of December 2007 and January 2008. The excessive rainfall resulted in no construction works in January 2008 and rework taking place in February. Excessive wind also delayed the liner installation process, resulting in completion in October 2008.

3.2.1 Earthworks

The embankments were formed using cut to fill methods and were compacted as per specification. The basin was constructed at a 1:18 slope to the outlet point. The initial side slopes were roughly formed by an excavator. A skidsteer on rubber tracks, capable of navigating 1:2 side slopes, was used to shape the slopes to a surface finishing suitable for liner placement.

The subsoil drainage system on the side slopes, consisting of filter sand within geocells, was included on the northern and eastern sideslopes, as the direction of groundwater flow is south-westerly. Additional allowance was made should more subsoil seepage be found once the basin had been formed. The excessive rainfall experienced aggravated the perched water table found between 2 to 3m below ground level. Additional subsoil drainage measures were required to be installed and commissioned immediately. The original construction plan was to commence construction at the highest point of the basin and work towards the lowest point, closely followed by the liner installation. It was challenging to address the additional drainage measures required without having the entire basin constructed before the liner installation commenced.

For each section of construction a temporary sump for the storage and removal of subsoil water was created. The additional removal capacity was achieved by fingers of geotextile and sand 'sausages' 500mm deep traversing laterally and vertically on the eastern slope and connecting to the toe drain. The placement of sand on the slopes was mainly by the skidsteer depositing it in the right position and hand labour spreading it within the geocells.

The large reinforced concrete sump was initially positioned at the north-eastern corner of the basin just outside the embankment. The 16m deep excavation for the sump created a recess for groundwater to collect in. Piping occurred with jets of groundwater flowing in after heavy rainfall. This created side wall instability; the main method of failure involved blocks of materials constantly failing into the excavation. Initially the excavation was enlarged by flattening the slope of the excavation face but the problem persisted. Eventually, the excavation could no longer be enlarged as it had reached the property boundary. The solution involved moving the sump into the embankment which meant that its depth would now extend to 21m.

As the construction had progressed to the lowest point it was time to construct the northern embankment which would block the main access into the cell. The result was that the main entry and exit would now be at the south-eastern corner where a ramp was included in the design. Since Cell 7 was to act as a lagoon, the ramp was not designed for heavy traffic, rather temporary entry. Traditionally, at the Site B landfill site, the ferricrete horizon above the sandstones is suitable for use as a wearing course once blended with ash, ie G5 standards. On Cell 7 however, the contractor found it difficult to achieve this upon placement. Lime was then added to the blend after laboratory testing returned with positive results, but still the ramp was not holding up due to the steep gradient and the heavy traffic. It was not feasible to commercially source a better material just for construction traffic and so for the period until the end of construction the ramp was reworked as often as required.

The stabilised ballast layer was designed to extend at least 1.5m above the toe of the basin. A trial section was carried out on the southern side. It indicated that the slope was too steep and the stabilised sand would crack and crumple as it dried out. The ballast layer was hence stopped at the edge of the side slope leak detection drain.

3.2.2 Liner Installation

The liner installation was complicated by the interface between the earthworks and lining contractors due, especially, to the progressive method of construction and to the many layers of geomembrane. Two anchor trenches were required with an additional one at the ramp where a geogrid layer was anchored and backfilled with concrete.

The most critical part of the installation was at the lowest point where three of the four gravity outlet pipes, leading to the reinforced concrete sump, penetrated the liners. Special flanges had to be manufactured for the outlet pipes. The contractor had to ensure that the levels were accurately controlled so that the two flanges would be aligned at the joint. This was difficult considering the basal lining system would have local depressions to accommodate the size of the barrel assembly.

Special flanges were also required for the installation of the sump barrels. The alignment of the side slope collection pipes and the gravity pipe flange was complex and difficult to achieve accurately.

The lining contractor had difficulty in welding the liner onto the barrel due to the difference in thickness between the two. The barrels had to be sent back to the pipe manufacturer who had to include ‘lips’ on the pipe onto which liner could be welded.

4. CONCLUSION

The construction of these two cells has shown that steep side slopes in lagoons lead to the following challenges:

- Difficulty in shaping the embankments and achieving surface finish suitable for liner placement.
- The placement of compacted clay layers is not possible.
- Liner placement on the slopes becomes difficult.
- Access ramps either become steeper or additional, often expensive, measures have to be employed.
- Multiple geomembranes in contact with one another become vulnerable to damage, especially during the working of material above them.

- Complexity of liner penetrations is increased.

The designers are of the opinion that although it is possible to construct lagoons with steep slopes, the challenges require strict quality control and expert skill from both the earthworks and lining contractors.

Where other measures to optimise waste filling volume within a site’s permitted boundary exist, these should be given precedence over steep internal side slopes.

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