TWO SLIDES THAT DAMAGED PARTS OF A LINING AT BISASAR ROAD LANDFILL, DURBAN

JON PASS and CLIVE WILSON
Wilson & Pass Inc, Consulting Civil Engineers
Durban, 14 Palm Springs, 155 Ridge Road, Durban

SUMMARY

This paper describes two slides of the liner protection layers at the Bisasar Road Landfill in Durban. The first failure occurred immediately after a short period of heavy rainfall while the next some 18 days later with no rain having fallen in this interim period. The lining system analysis is described and the cause of failure identified.

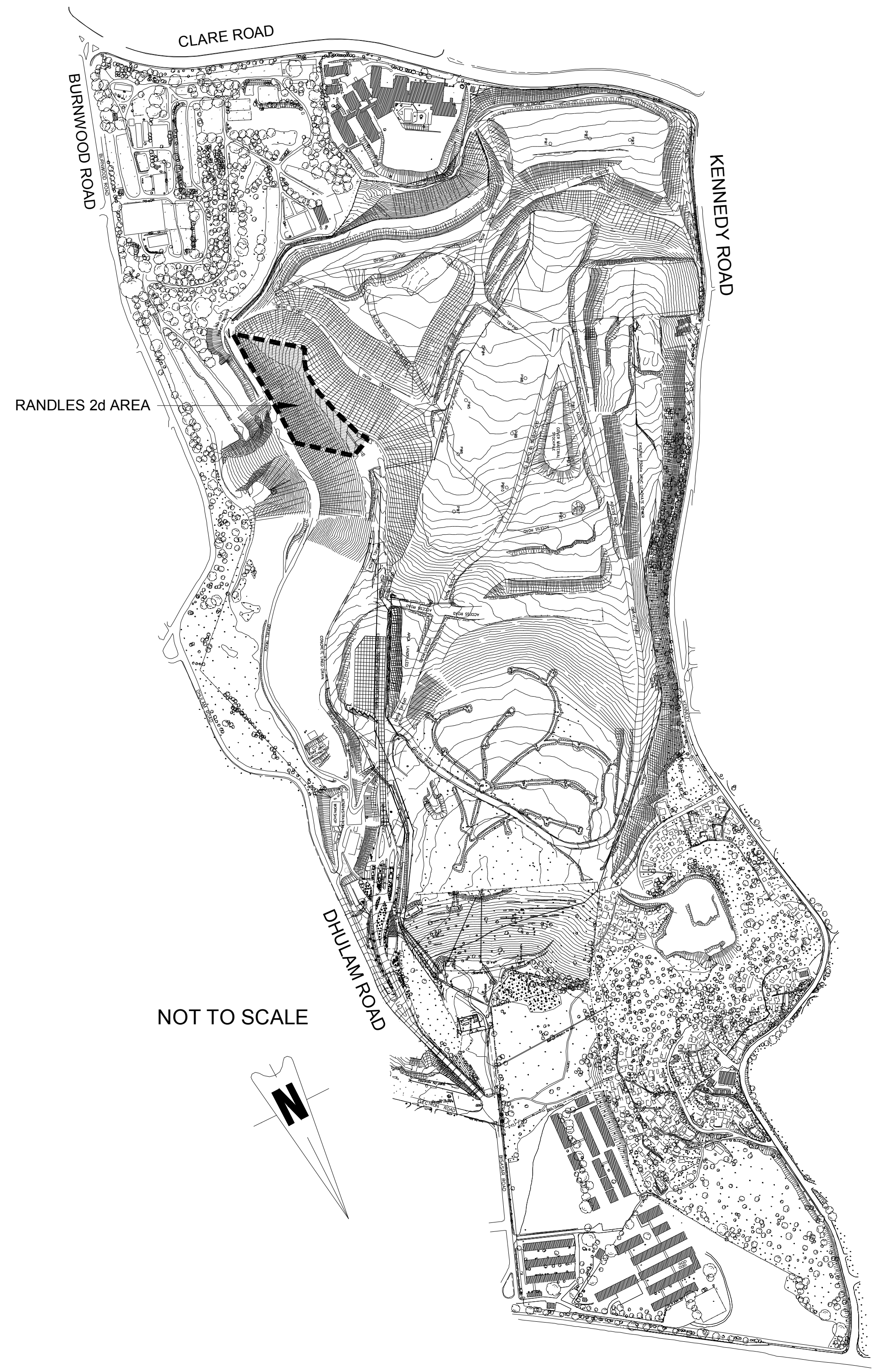
1. INTRODUCTION

During 2003, a moderately steeply sloping part of the Bisasar Road Landfill Site in Durban referred to as the Randles 2d Cell, and extending over about 11000 square metres, was prepared to receive municipal waste, by placement of an impervious lining. The location and extent of this cell within the wider landfill site is illustrated in Figure 1.

Two slides occurred in the lining itself on the steepest and highest part of the slope after about 80% of the cell had been lined. The first occurred on 24 June 2003, during heavy rain, and the second 18 days later, during placement of a coarse stone drainage layer, very close to the first slide, although no rain had fallen since the first event.

Both of the slides entailed displacement of the upper layers of the lining (a stone drainage layer and a cemented soil protection layer) over the primary impervious element, the HDPE geomembrane.

Figure 1. Bisasar Road Landfill Site showing the Location of Randles 2d Cell



2. DESIGN OF IMPERVIOUS LINING

The lining system, which is illustrated in Figure 2, consisted of the following elements, to be placed over the moderately steep ground slope (up to about 1 V : 2.2 H or 24°). From the top:

1. A 200mm thick, *Drainage Layer*, consisting of almost single size (>53mm), crushed hard stone aggregate. This highly permeable and porous medium was intended to drain leachate from the waste.

2. A 125mm thick, *Protection Layer*, consisting of fine-grained sand, mixed with cement to impart limited compressive strength (about 1.0 MPa). The primary purpose of this layer was to protect the underlying impervious, HDPE geomembrane from damage by the overlying, stone Drainage Layer, or by waste. Its secondary purpose, in conjunction with the underlying Geogrid, was to support the stone Drainage Layer, to prevent it from sliding off the steep slope.

3. A "*Geogrid*", comprised of woven strands of synthetic fabric that exhibited significant tensile strength. This fabric facilitated placement of the cemented sand, by preventing it from sliding off the slope before it hardened, and contributed later, in conjunction with the hardened Protection Layer, to retain both that layer and the overlying Drainage Layer on the slope. To ensure the supporting function of the Geogrid, it was anchored in a concrete-filled trench at the top of the slope, as illustrated in Figure 3.

4. A "*Geotextile*", comprised of a non-woven, needle-punched, synthetic fabric that acted as a friction break to limit tension and possible stress cracking in the HDPE Geomembrane below, and as a cushion to limit damage during placement of the overlying Protection Layer (or rather the equipment use to place it).

5. A "*Geomembrane*", comprised of 2mm thick, high density, polyethylene (HDPE), which prevents infiltration by leachate into the ground beneath the landfill. The Geotextile and the Geomembrane were both also embedded in the anchor trench at the top of the slope.

6. A *Base Layer*, consisting of 150mm of fine-grained, compacted, cement stabilized sandy soil, that provided a firm, uniform surface upon which to place the Geomembrane.

7. A *Selected Subbase Layer*, formed by scarifying and/or spreading and compacting 200mm of the insitu soil over the trimmed, sloping, natural ground surface. This layer facilitated placement of the overlying Base Layer, by providing a firm uniform base.

Figure 2. Bisasar Road Landfill Site Randles 2d : Geomembrane Lining System

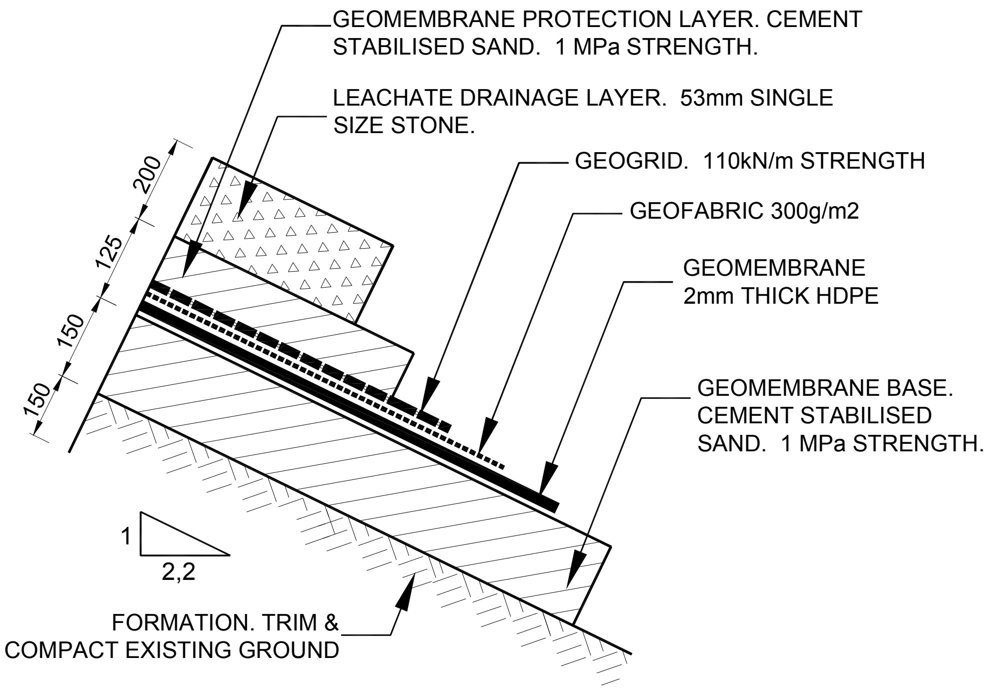
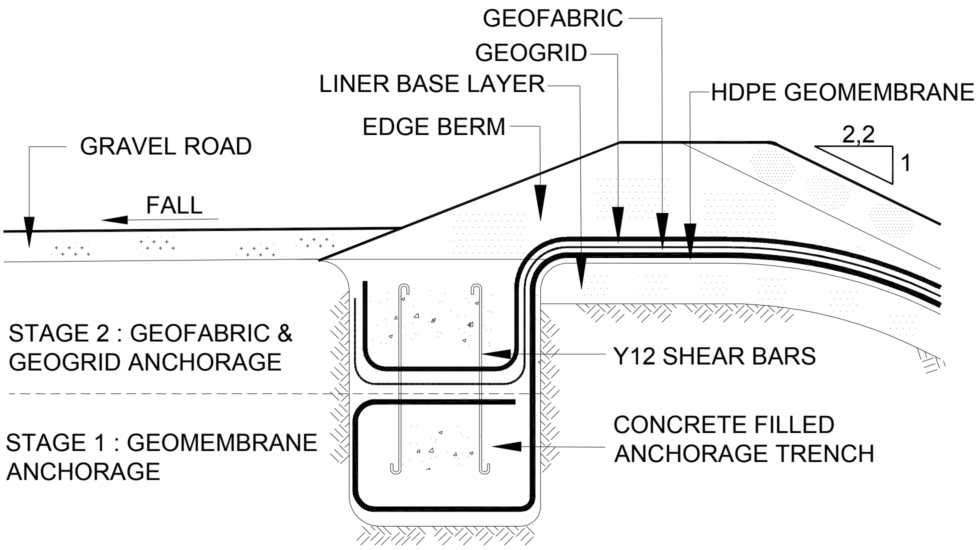


Figure 3. Bisasar Road Landfill Site Randles 2d : Lining Anchorage System



Prior to placing the lining, the slope was first prepared by:

a) trimming off of pronounced protrusions, and/or filling of depressions to eliminate the possibility of inducing undesirable stresses in the HDPE Geomembrane, as might arise if it were draped over an irregular surface;

b) Installation of subsurface drains, to intercept groundwater seepage to surface on the slope, wherever there were indications that it might do so, and thus to prevent development of hydraulic pressures under the cell lining.

3. CONSTRUCTION OF THE LINING

After trimming the slope and placing the Base Layer, the Geomembrane, the Geotextile and the Geogrid were successively deployed by unrolling strips down the slope, that were restrained in the anchor trench at the top.

Suitable sand mixed with cement was thereafter delivered in bulk to the top of the slope for use as the Protection Layer. Such material was pushed down the slope over the Geogrid by a light bulldozer in 10m to 15m wide strips, and compacted by a light roller, before being left to cure.

The Drainage Layer was also constructed from the top of the slope, where stone was again delivered and then dozed down the slope, over the Protection Layer.

4. SLIDING FAILURES

Heavy rain fell on Bisasar on the evening of 24 June 2003 (including 27mm in only 80 minutes). A strip of the Protection Layer, about 14m wide and extending over the whole height of the slope (20m vertically; 55m inclined or slope distance), slid to the bottom, sometime that night. Figure 4 shows a view of the slope the day after the slide. Areas on either side were damaged but remained in place.

The lower part of the strip of the Protection Layer affected by the slide had been placed the day before the slide took place. The cement in the material had not, therefore, yet fully cured. The remains of the soft, uncured, material were evident in the slide debris, as it had deformed in a plastic manner typical of un-cemented, or poorly cemented material. The balance of the debris, derived from the slightly older parts of the layer higher up the slope, which had cured to a greater degree, broke into larger fragments in a more brittle manner.

The stone Drainage Layer had <u>not</u> yet been placed over the area affected by this first slide.

The Geogrid and Geotextile under the cemented sand Protection Layer both tore away from the anchorage trench at the top of the slope, and also came down.

Figure 4. Bisasar Road Landfill Site Randles 2d : View of Slope after First Slide

A Second Slide took place on 12 July 2003, after nearly 3 weeks without rain. A strip of the Protection Layer <u>and</u> Drainage Layer, about 24m wide, and again extending over the whole height of the slope, slid down and came to rest over about the lower third the slope.

The strip affected by the Second Slide was separated from that affected by the First Slide by an intermediate, 15m wide strip, as shown in Figure 5. The intermediate strip remained in place, but was severely cracked.

The part of the Protection Layer affected by the Second Slide had been placed 4 to 5 weeks before this event, and had therefore cured.

Stone was being placed for the Drainage Layer over the area affected by the Second Slide at the time it occurred. Almost the entire strip had been covered with such stone when the slide occurred. Stone covered only about 50% of the adjacent strip, however, which became cracked but remained in place.

After removal of the slide debris it was found that the displaced part of the lining extended onto the almost horizontal bench at the bottom of the slope, up to an edge roughly midway across that bench. The material beyond that edge had not been displaced.

Figure 5. Bisasar Road Landfill Site Randles 2d : View of Slope after Second Slide

5. SLIDING STABILITY

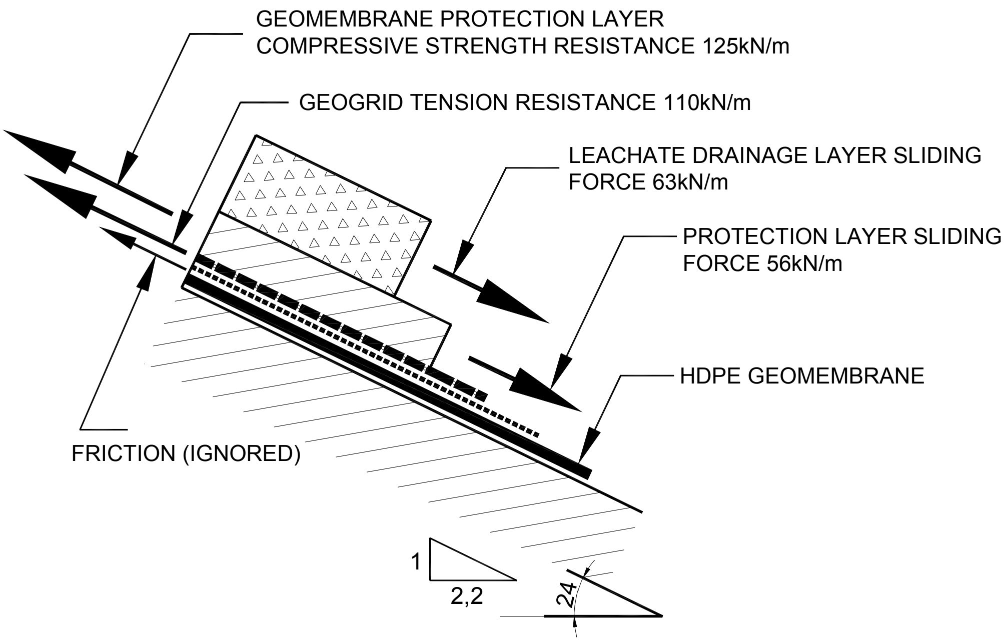
There is little frictional resistance to sliding between geofabric and HDPE, such as the specified Geotextile, and Geomembrane respectively. Such friction was therefore discounted in regard to potential sliding of the Protection and Drainage layers over the HDPE. Sliding of those layers was instead intended to be prevented, before solid waste was placed, by the combined effects of compressive thrust within the Protection Layer, plus tension in the Geogrid, which would together resist the downslope component of the combined weights of the Protection and Drainage layers.

After solid waste had been placed it would attach to those layers, thus further constraining them (provided such waste was placed from the bottom of the slope).

Support of the cemented sand Protection Layer, to prevent it sliding down the slope, would require a force in the plane of the layer, directed up the slope, equal to 56 kN per metre horizontally, computed as illustrated in Figure 6. The corresponding total force necessary to subsequently support both the Protection Layer and the Drainage Layer together would amount to 119 kN/m.

Tension developed in the Geogrid, plus compressive thrust developed simultaneously in the Protection Layer, could provide such in-plane supporting forces. As the rated tensile strength of the Geogrid was specified to be 110kN/m, it could support the Protection Layer by itself, as indeed it had to do, until the cemented sand cured sufficiently to develop compressive resistance. Thereafter, the Protection Layer would provide most of the necessary resistance in compression to support the weight of the Drainage Layer.

Figure 6. Bisasar Road Landfill Site Randles 2d : Forces in Liner System



6. UPLIFT WATER PRESSURE

Relatively small water pressure (equivalent to a “head” of only 0,5m) could potentially lift the entire combined lining. Subsurface drainage was therefore installed to intercept any groundwater seepage beneath the slope, to prevent development of such pressure under the Geomembrane.

Similar small water pressure above the Geomembrane, could also cause damage, if it were sufficient to lift the Protection and Drainage layers. Accumulation of water under the Protection Layer had therefore also to be prevented.

Ingress of water from below was prevented by the HDPE. Water might, however, in principle, either seep or leak directly through the Protection Layer, or infiltrate at the top of the slope where the layer terminates.

Seepage or leakage through a layer such as the Protection Layer, due to direct rainfall and runoff, could not result in excessive uplift pressures below it, provided its permeability was no greater over the lower part of the slope than over the upper part. In such case, hydraulic pressure is relieved by seepage up through the layer at the bottom of the slope, where water drains out as fast as it seeps in through the layer higher up the slope. This is true irrespective of the actual degree of permeability, or whether flow takes places through cracks, provided only that the overall, or average permeability of the layer is roughly uniform, or at least is not greater over the higher part of the slopes, than it is lower down.

Ingress of water under the top edge of the Protection Layer was initially thought to be unlikely, provided the access track was not flooded for a prolonged period. As shown in Figure 3, the Protection Layer was intended to lap over the anchor trench, to prevent direct ingress by rainfall and runoff. In the event, however, this was the route through which water penetrated to cause the slides.

7. CAUSE OF THE SLIDES

7.1. The First Slide

As the First Slide was clearly associated with the rain that fell on the evening of 24 June 2003, it had to have been the effects of water that infiltrated between the Protection Layer and the HDPE Geomembrane, that either added to the forces that had to be resisted, or reduced the capacity of the resisting mechanisms.

Examination of the aftermath of the slide indicated streaks over the upper parts of the exposed HDPE Geomembrane, evidently due to flow of water over it, which appeared to have gained entry at the top of the slope, as seen in Figure 4. Inundation of the access track above the slope, due to impeded drainage of runoff, was clearly the source of such water.

Two runoff streams met on the access track above the part of the slope where the First Slide occurred. A drainage channel along that portion of the track had furthermore become blocked.

If water could infiltrate between the Protection Layer and the HDPE Geomembrane more rapidly than it could exit, it would have accumulated in the Geotextile between them, and hydraulic pressure would consequently have developed therein. Such pressure would have eliminated any small frictional resistance to sliding that may have been contributing to stability once such pressure equated to the weight of the Protection Layer (the Drainage Layer had not yet been placed over the affected area).

Such hydraulic pressure would furthermore have saturated the Protection Layer, caused porewater pressures to develop within it, and resulted in seepage up through it, over the lower part of the slope. This would have reduced the resistance of the Protection Layer to compressive thrust (i.e. have softened it), particularly where the cement had yet to cure. This effect should not however have been of great importance by itself, because the layer had evidently been stable when it was placed, before it had developed any compressive strength.

Accumulation of water beneath the Protection Layer would not have ceased when the growing pressure exceeded the weight of that layer. Thereafter, such pressure would have lifted the layer, thus creating an opening between it and the HDPE Geomembrane, and continued thereafter to progressively “inflate” such opening. Such inflation would have greatly magnifying the tension force in the Geogrid, eventually causing it to tear away at the top of the slope, just below the anchor trench, thus precipitating the slide. Such dislocation and sliding would incidentally have allowed drainage and thus relieved the excess hydraulic pressures. While this would have been too late to forestall the slide, it would have halted progressive overstressing of the Geogrid in the adjacent areas.

7.2. The Second Slide

The Second Slide took place nearly 3 weeks after the First Slide, while stone was being placed on the affected area for the Drainage Layer. As shown in Figure 5, stone had been placed over most of the area affected by the Second Slide (on the left of the photograph).

The triggering mechanism for the Second Slide evidently differed from that for the First, as rain had not fallen in the intervening period.

Placement of stone for the Drainage Layer would more than double the in-plane, downslope force that had to be resisted to prevent sliding. As the capability of Protection Layer, aided by Geogrid, to support the Drainage Layer had already been proven over most of the cell, their capability to do so in the area affected by the Second Slide had evidently been compromised.

The water that caused the First Slide by infiltrating under the Protection Layer could not have been confined beneath just the strip affected by that slide. It must therefore have been present under a wider area, including under the area later affected by the Second Slide. Consequent damage, in the form of tension and compression cracks, were indeed observed in the adjacent parts of the Protection Layer that remained on the slope after the First Slide, including in the area subsequently affected by the Second Slide, although it was not appreciated, at the time, that this had seriously reduced the strength of the overall system.

Such crushing damage therefore affected a wider area during development of the First Slide, than actually slid at that time. The process was evidently arrested in the adjacent areas (such as that later affected by the Second Slide), due to drainage and thus relief of the excess hydraulic pressures, as the First Slide took place.

The supporting capacity of the Protection Layer had been so reduced by the damage that it could not support the Drainage Layer when it was added, as it could ordinarily do, and had already done successfully over 80% of the cell. The Geogrid, however, had, until then, been capable of performing its function, of supporting the (damaged) Protection Layer.

The cause of the Second Slide was therefore damage to the Protection Layer induced during the First Slide, by the mechanism that caused that slide, which thus precluded it from performing its function of supporting the Drainage Layer when it was placed.

8. BUCKLING

The potential for buckling of the Protection Layer, which was very thin in relation to its length down the slope, due to the in-plane compressive thrust it was subjected to, was considered. However, the weight of the Protection Layer (and of the Drainage Layer, where it was present), added to the effect of the Geogrid, were determined to be sufficient, in the given case, to prevent such buckling.

Buckling could, in principle, occur in the form of "crumpling" of a thin lining near the bottom on a high slope, in other circumstances (for instance where the Geogrid was absent). However, where a Geogrid is present, as in this case, its restraining effect would first have had to be overcome by its failure in tension, before high compression stresses could develop in the Protection Layer, and either such buckling failure or compressive overstress could ensue thereafter. Successful completion of the lining over 80% of the cell area before either of the slides described here took place, demonstrated that the Geogrid was adequate to support the Protection Layer in the normal course of events.

9. RECONSTRUCTION OF THE LINING

After both the First and the Second Slides, the affected parts of the lining were re-constructed. The Protection Layer was, however, in these cases, constructed by building up from the bottom of the slope, so that each additional panel was supported from below as it was placed, by material that had already partially cured.

The Protection Layer had however already been successfully completed over about 80% of the Randles 2d Cell, by constructing in strips from the top down. It was recognized that that method entailed certain undesirable risks - such as sole reliance upon the Geogrid to support the Protection Layer over the whole slope height until it had cured sufficiently to contribute effectively, and greater tension in the Geogrid than would exist if the Protection Layer were placed in lifts from the bottom of the slope.

The following additional measures were also incorporated into the reconstructed portions of the Protection Layer, to increase their margin of security:

(a) Stone-filled pockets through the Protection Layer over the lower part of the slope, through which any water that might infiltrate beneath it could drain.

(b) 400mm wide, concrete ribs, cast in slots formed in the Protection Layer over the lower part of the slope, to increase total resistance to thrust in the plane of the layer.

10. CONCLUSIONS

The slides described in this paper occurred despite appreciation of the vulnerability of the intended thin lining, in case of water ingress. This reinforces important lessons learned from many other failures also instigated by unanticipated water ingress, that:

a) it can often be nearly impossible to predict where water will penetrate structures unexpectedly and cause damage, and

b) that it can often be desirable to incorporate design features that anticipate such ingress, as far as possible, despite the risk thereof appearing to be remote (such as the drains and ribs described in the previous section).

This case history also illustrates two other principles of careful construction management that:

1. Working methods should be consistent with the design of the works being constructed, to preclude damage to elements before they are complete, or, more generally, to avoid development of conditions that were not considered in the design.
2. Where failures occur, the materials concerned may be damaged in ways not anticipated in the design, and may thus harbor defects that are not apparent without very detailed and careful examination and analysis.