

# Geomembranes, Geotextiles and Slope Stability

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**SUMMARY** Stability and interfacial friction considerations of geomembranes and geotextiles are discussed with particular reference to a sliding failure of a gold mining heap leach pad.

## 1.0 INTRODUCTION

A significant development in gold ore processing technology over the past 10 years has been the adoption of the heap leaching route for oxidised ores. In concept this involves the stacking of crushed ore on prepared pads for irrigation with a specially prepared cyanide solution. This solution percolates through the heap and can be collected as 'pregnant' liquor in edge drains for further processing to extract the gold. After gold extraction the solution is adjusted prior to recycling to the ore heap. For amenable ores the system offers significant advantages over the conventional grinding/leaching route with respect to energy demand and water demand.

Such heap leach stacks can be 30 metres high with pad areas of several hundred thousand square metres. Ore placement is often by back dumping from dump trucks with conveyor systems sometimes being employed.

A typical system is shown in Figure 1.

A critical component of the heap leaching system is the base liner which must provide a secure means of containment and direction for the leachate. This requirement derives both from the economic aspect in preventing loss of gold bearing liquor, and from the environmental viewpoint in preventing soil contamination by cyanide. Typically the liner is constructed as a heavy duty plastic membrane laid on a suitably prepared base, and installation of the membrane must ensure complete integrity of the lining system.

Typically a heap leach mineral extraction project is seeking to exploit a relatively low grade resource and its viability is often at the lower limit and dependent on the minimisation of construction and operating costs. Since the supply and installation of the pad liner is a major capital item its design must be carefully considered in order to maximise economy while maintaining appropriate factors of safety, which are normally somewhat less than those applied to typical 'permanent' civil engineering works.

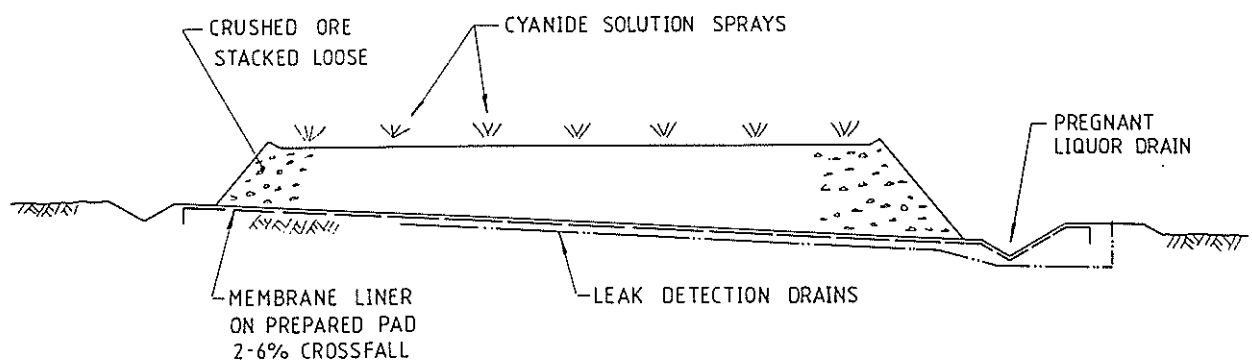


Figure 1. Section Through Typical Heap Leach

## 2.0 STABILITY AND OPERATIONAL CONSIDERATIONS

The design, construction and operation of a heap leach facility involves a number of compromises which require consideration and appropriate supervision to ensure that satisfactory results are obtained. The actual behaviour of different ores can also vary and lead to a reduction in stability safety factors.

### 2.1 Ore Stability

The desire to maximise gold recovery dictates that the ore heap is stacked with faces as steep as possible and thus the frictional resistance to sliding at the base is partially mobilised and the degree to which it is not mobilised is the effective safety factor in the structure.

The method by which the ore is placed also affects the stability of the ore heap. Again considerations of gold recovery make it desirable to build the heap close to full height at the starting point and to gradually work the batters out by dumping and pushing. A more stable initial heap body can be obtained by methods such as:

- (i) initial part height construction over the major part of the pad with subsequent topping up to full height, or
- (ii) provision of horizontal benching particularly in the downhill faces of the heap.

These variations in technique will affect the gold recovery particularly during start-up, an important consideration for capital intensive projects looking for an early cash flow.

Another complicating factor can be the tendency for the crushed ore to acquire a degree of cementitious binding as the solution is percolated through it. This can influence the ore to act less like a granular material and more like a unified cohesive mass. From the point of view of heap stability cementation can be a considerable advantage but it also has the effect of reducing the solution percolation rate and from a gold recovery viewpoint is usually undesirable.

### 2.2 Pad and Interface Behaviour

Heap leach pads are normally constructed with a fall of 2-6% depending upon such factors as existing topography, length of flow paths, percolation rates and overall layout. Pondage for ore bearing (pregnant) solution and take-off channels are normally at the downhill side so it is

normally easier to commence heap construction from the uphill side in spite of the improved stability possible by working from the low side and pushing the ore heap up the slope. Horizontal benching to improve stability has been used in solid waste dumps with synthetic liners but such aids have not been used in heap leaching.

The geomembranes used for heap leach pads are typically thin HDPE extruded sheets with very smooth surfaces, limited tensile capacity and puncture resistance. It is therefore normal to require the prepared base for the liner to offer a smooth surface without protrusions. Improved resistance to puncture can be obtained by using a thick non-woven geotextile underlay or overlay but as the case study which follows illustrates this can severely reduce the friction along the critical interfaces.

## Friction Surface Characteristics Direct Shear

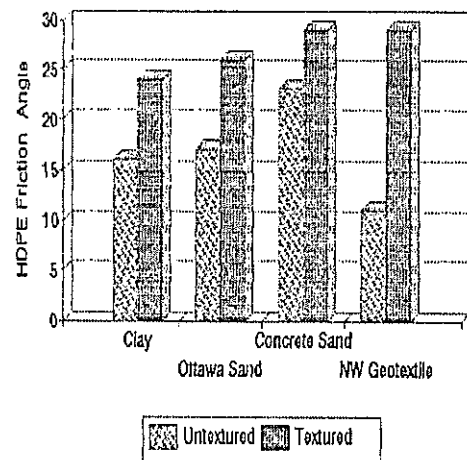


Figure 2. Geomembrane Friction Angles

Friction angles for smooth sheet extruded HDPE liners have been established by shear box testing (e.g. Cadwallader)(1) to be around 15° for clays, 25° or more for sands but reducing to 11° or less for geotextiles depending on their characteristics. This data is summarised in Figure 2 which also shows the capability of co-extruded HDPE sheet with textured surfaces to improve the friction angles for soils and particularly for geotextiles.

There is also a complicating factor for smooth liners, in that once sliding has occurred there is a significant reduction in the friction angle due to a 'polishing effect'. This is discussed by Mitchell et al (2).

### 2.3 Design and Supervision

As with many other projects contractual arrangements may mean that the designer of the heap is not involved through the construction and operational phases and is not able to observe the behaviour of the heap during loading and operation. If a sliding failure is to occur it will normally be signposted by cracking at the top of the heap and wrinkling of the geosynthetic materials at the toe. It is essential that there is responsible and aware supervision during the loading and initial operation phases that is on the lookout for these telltale signs.

### 3.0 CASE STUDY LEACH PAD FAILURE

A recent example of a heap leach pad was constructed in Queensland, where a relatively small scale installation was required to provide for economic processing of a gold bearing 'gossan cap' overlying a deeper base-metal ore body. A leach pad was designed and constructed 100 metres by 210 metres long, consisting of graded and compacted in-situ material, to 3.6% maximum crossfall to receive a fully welded HDPE membrane liner 1.0mm thick.

The pad surface was specified to be finished smooth and unyielding, and free of rocks, stones, sticks or other debris in the top 100mm. However the pad as completed by the earthworks contractor failed to meet these requirements. Importation of suitable clayey sand or loam as a bedding material was considered but associated construction delays and cost penalties led to the decision to

adopt instead a geotextile layer as a protective cushion to the underside of the membrane, and Polyfelt TS600 nonwoven polypropylene geotextile was installed.

Following completion of the liner installation construction of the heap was commenced from the uphill end using conventional end dumping and dozing techniques. As the heap progressed down the slope an extensive series of wrinkles formed in the liner in front of the advancing ore, (Figures 3,4) indicating the likelihood of distress in the liner beneath the heap. However due to the inexperience of the operators this potential was not recognised, and cyanide spraying commenced. Large quantities of pregnant solution were subsequently intercepted in the leak detection drains, and spraying was stopped. When ore was removed, extensive tears in the liner were revealed, indicating clearly the leakage path. To avoid further contamination the stacked ore was immediately removed under the direction of the regulatory authority to an adjacent tailings containment, and the base was ripped and lined to neutralise the cyanide.

Inspection of the underside of the failed liner revealed directional polishing marks consistent with relative sliding movement of the liner over the geotextile, down the slope of the pad.

Investigations were carried out by the various parties to the construction, and the consensus was that the primary cause of the failure was low relative friction between the membrane and the geotextile with consequent overstressing of the membrane in tension. This mechanism is analyzed below.

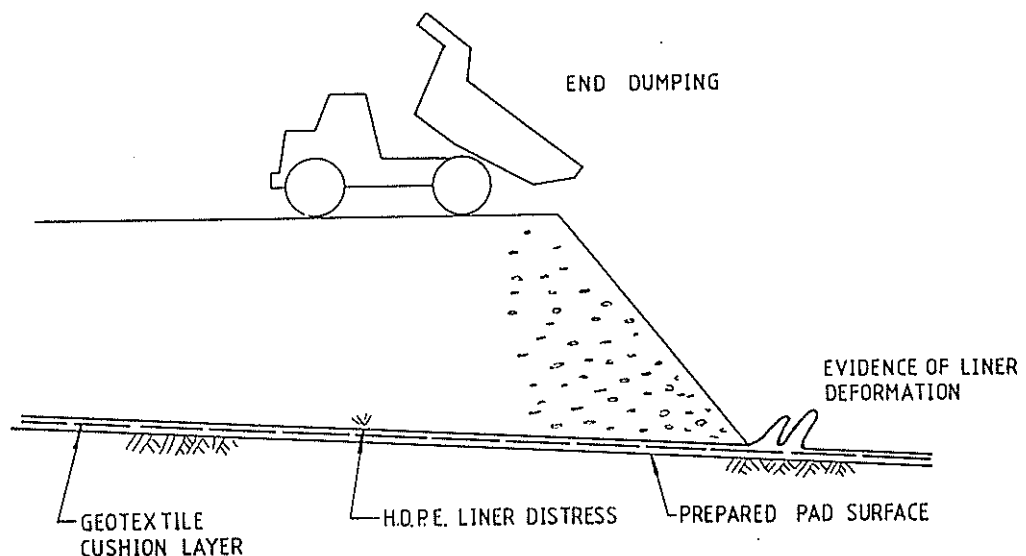


Figure 3. Case Study Heap Construction

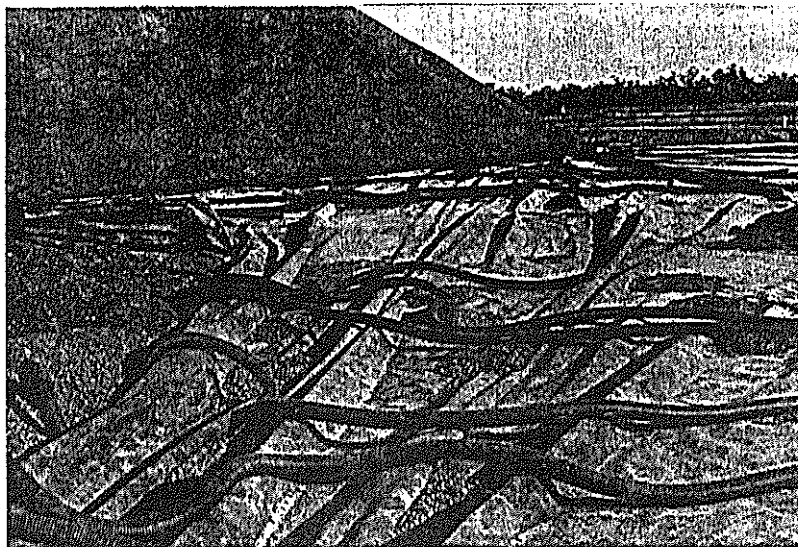


Figure 4. Case Study Liner Deformation

At least one similar experience in the mining sector has been reported from the USA by Thorndycraft (3) where a pad constructed in similar fashion (i.e. HDPE membrane over geotextile) at a gold mine in Nevada failed at 7% base slopes, after similar pads built at 6% and less had survived.

Failure on a 7% base slope suggests that installations on 6% would have rather marginal factors of safety.

The question of geomembranes and slope stability has been a major interest in relation to landfills with incidents such as the Kettleman Hills failure prominent. Kettleman Hills involved a 6 hectare hazardous waste landfill up to 30 metres high with three layers of HDPE liner and various other geosynthetic layers. There was a substantial sliding failure in 1988 as reported by Mitchell et al (2). A recent overview of liner stability on slopes with particular reference to landfills is given by Matichard et al (4).

#### 4.0 CASE STUDY FAILURE ANALYSIS

Consider the forces acting on the toe of a heap being constructed to height  $H$  on a base of slope  $\alpha$ ,

- with  $\Gamma$  = material bulk density
- $\theta_r$  = angle of repose
- $\theta_i$  = angle of internal friction
- $\theta_b$  = angle of friction at base  
as shown in Fig 4.

Assuming active pressure conditions prevail, and neglecting any surcharge effect or cohesion, which is typically small for an uncompacted crushed ore., the horizontal force per unit width acting on the wedge is

$$P_h = \Gamma \cdot H^2 / 2N_\theta$$

where  $N_\theta = \tan^2 (45^\circ + \theta_i/2)$

The vertical force acting on the wedge is the weight

$$P_v = \Gamma \cdot H^2 / 2 \tan \theta_r$$

The total force to be resisted along the slope at the base is then

$$P_r = P_h \cdot \cos \alpha + P_v \cdot \sin \alpha$$

The limiting force that can be mobilised by friction at the base is

$$P_f = P_v \cdot \cos \alpha \cdot \tan \theta_b$$

The resulting tension in the membrane is

$$T_m = T_y$$

Thus the factor of safety against sliding is  $FOS = (P_f + T_y) / P_r$

A minimum value of 1.5 is recommended for design. A calculated value less than 1.0 indicates incipient failure.

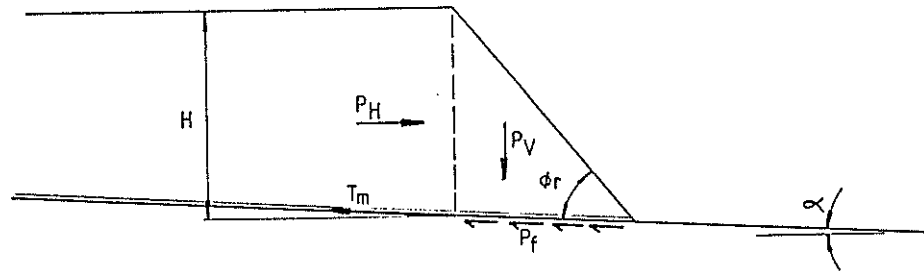


Figure 5. Forces Acting on Toe of Heap

For a heap constructed in thin layers above the liner the maximum tensions would occur near the batter points as illustrated. However for heaps built by end dumping (which is favoured to minimise heap compaction and to maximise permeability), the maximum loads are locked in across the width of the heap.

Using typical parameters for the case study heap :-

$$\begin{aligned}
 H &= 5.0\text{m} \\
 \gamma &= 18 \text{ kN/m}^3 \\
 \alpha &= 2.05^\circ (= \tan^{-1} 0.036) \\
 \phi_r &= 37^\circ \\
 \text{and } \phi_i &= 33^\circ
 \end{aligned}$$

we derive

$$\begin{aligned}
 P_H &= 66.3 \text{ kN/m} \\
 P_V &= 298.6 \text{ kN/m} \\
 \text{and } P_f &= 77.0 \text{ kN/m.}
 \end{aligned}$$

Now for  $\phi_b = 11^\circ$  (geotextile to HDPE).

$$P_f = 58.0 \text{ kN/m.}$$

and  $T_y = 16.7 \text{ kN/m}$  for 1.0 mm HDPE

The calculated factor of safety against sliding is  $(58.0+16.7)/77.0 = 0.97$  indicating incipient failure.

Surcharge effects and applied horizontal loads from dump truck and dozer operations on top of the heap will tend to increase these effects locally.

By comparison for  $\phi_b = 19^\circ$  for HDPE to a granular bedding material,

$$P'_f = 102.8 \text{ kN/m}$$

and the calculated factor of safety is  $(102.8+16.7)/77.0 = 1.55$  which is satisfactory.

## 5.0 SOME REMEDIES AND PRECAUTIONS

It will be evident that the tight cost considerations which are inherent in heap leach mining will ensure that ore heaps are usually built close to the appropriate safety factors. Where circumstances arise that reduce the safety factor below acceptable levels a number of avenues are available to preclude this. The costs associated with the various alternatives will need to be evaluated for each application

### 5.1 Work from Low Side.

If it is possible to work from the low side stacking the ore up the hill the risk of instability is reduced. Starting from the low side may lead to a short delay in gold production.

### 5.2 Bench Low Side Slopes

Providing horizontal berms or benching, particularly to the downhill slopes will effectively reduce the mass of ore trying to slip and so improve stability. Benching will effectively reduce the volume of ore exposed to leaching

solution but the edges of the heap are often difficult to treat and are often used for poorer quality ore anyway.

### 5.3 Build to Part Height First

By building the heap to only part of its full height initially stability can be maintained in the initial phase and the ore will have settled and may be partly cemented when the second stacking phase is carried out. The gold production rate will be reduced because less ore will be exposed to solution in the early phase and because of a reduced percolation rate in the latter phase.

### 5.4 Use Textured Liner

Using a textured liner will increase the critical base interfacial friction and improve stability. Textured liners are more expensive to manufacture but the extra material cost may be offset by other factors such as reduced pad preparation if a geotextile is to be used.

### 5.5 Thicker Liner for Tensile Capacity

Having a thicker liner with increased tensile capacity will enable the liner to provide greater resistance to sliding and will also provide improved puncture performance which may be reflected in reduced base preparation costs. Liner cost is directly related to thickness.

### 5.6 Reinforce Heap

Stronger liner is a fairly inefficient way to make the heap more stable - there are many other geosynthetics such as geogrids and geotextiles able to do this more effectively. Some may also help to improve percolation rates and reduce the impact of fines migration and cementation. The extra cost of these materials may be partially offset by steeper faces and improved percolation.

### 5.7 Geotextile as Overlay

If a geotextile is needed to guard against liner puncture due to doubtful base preparation then it may be prudent to place it over the liner. If sliding occurs then the heap and geotextile can move without dragging the liner and early observation of this will enable suitable remedial action to be taken.

### 5.8 Build Pads with Opposing Slopes to a Common Valley

If a series of pads are built to slope towards a common valley with a suitable valley crossfall then the two pads can be built back-to-back and provide support to each other during all phases of construction and operation. On pads which involve substantial base preparation this variation should be possible with very little additional cost.

### 6.0 CONCLUDING REMARKS

Heap leach pads are by their nature close to the limiting factors for heap stability and care needs to be taken in assessing the interaction of different materials particularly at the critical base interfaces. This is especially so for changes due to circumstances that arise during construction and operation.

If sliding is going to occur it is normally slow to start and should be apparent from astute observation which will allow appropriate remedial action to be taken with minimal impact on cost or production.

### 7.0 REFERENCES

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2. Mitchell, J., Seed, R., and Seed, H. 'Kettleman Hills Waste Landfill Slope Failure. I: Liner-System Properties' ASCE Journal of Geotechnical Engineering, Vol 116, No. 4, April, 1990
3. Thorndycraft, R.B. 'Heap Leaching in Mountainous Terrain', Proceedings Perth International Gold Conference, Randol International Ltd., 1988.
4. Matichard Y., Delmas, P., Soyez, B., Girard, H, and Mathieu, M. "Stability of Lining Systems on Slopes' Sardinia '91-Third International Symposium on Landfills. University of Cagliari, Sardinia 1991.