

Heap leach pad design in very aggressive terrain

Carlos César, Anddes Asociados SAC, Peru

Javier Mendoza, Anddes Asociados SAC, Peru

Denys Parra, Anddes Asociados SAC, Peru

Abstract

Heap leach pad design in regions where terrain characteristics are particularly aggressive is carried out using the valley fill method. In Peru, most heap leach pad facilities are designed and constructed with the valley fill method; many of these facilities are in very aggressive terrain. Valley fill heap leach pads have also been used in very aggressive terrains in Argentina, Mexico, Colombia, Indonesia, and the Philippines.

Valley fill heap leach pad design in aggressive terrain results in high construction costs in most cases for several reasons. Earthworks represents up to 70% of total project costs in some cases. Other costs arise from the need for earthworks optimization and surface grading for soil liner and geomembrane placement; there is also significant settlement when massive fill platform is used or weak foundation remains, which requires a pre-camber to offset settlement. Difficulties in soil liner placement make it necessary to use geosynthetic clay liners (GCL) where soil liner cannot be placed. Geomembrane liner installation is complex on very steep slopes, and this complexity makes it necessary to ensure an efficient drainage collection system. Other costs are associated with the design of intermediate benches in areas cut for GCL installation and the reduction of leaching areas in first lifts in narrow valleys, which compromises initial mine production due to insufficient irrigation of the heap.

This paper presents experiences in designing and constructing heap leach pads in very aggressive terrain and considers technical criteria developed specifically for these conditions. These criteria have been successfully applied to heap leaching projects in Peru and also in Argentina, Mexico, and Colombia.

Introduction

The topography of some areas is very aggressive and unfavorable for heap leach pad design and construction. For example, mining projects in the Andes region typically operate at altitudes higher than 2,500 meters above sea level, where the only place available for a heap leach pad is usually a valley. In

such areas, the design of earthworks, liner systems, solution collection systems, and first lift stacking involve additional effort and specific design criteria that differs from those used in areas where terrain is much more favorable (for instance, in flat areas or at lower altitudes).

Based on our experience, several main aspects must be considered in designing heap leach pads in a region of very aggressive terrain: earthworks optimization, selection of areas for soil liner or GCL, pre-cambering design in massive fills or weak foundation, geosynthetics design and installation, intermediate benches, solution collection system design, and first lift issues.

Earthworks optimization

Earthworks optimization is one of the most important aspects of heap leach pad design in aggressive terrain; it helps to ensure proper stability for the entire facility and also helps avoid increasing construction costs. In very aggressive terrain, earthworks costs can represent up to 70% of total construction costs.

Foundation depth

Before starting the cut and fill work to grade the whole area for pad construction, a geotechnical engineer should define the foundation depth and determine excavation depth. Figure 1 shows a typical foundation plan, which is used by design engineers for generating the foundation surface and leach pad grading plans. This foundation plan is generated based on test pitting, which is carried out as part of the geotechnical field investigation program. The geotechnical engineer defines the appropriate foundation depth for reaching competent foundation soil in each test pit or trench, and then the design engineer uses this information to complete the final grading plan. The foundation plan must be optimized, especially at the base of the leach pad, to verify proper stability conditions for the whole heap.

After the grading plan is completed, the underdrain system design is developed. The final underdrain layout considers the final cut surface, which depends on a combination of cut surfaces between the foundation and grading.

Solution collection drainage plan

The leach pad grading plan must also include a drainage plan for collecting solution. This plan must direct drainage to the lowest spot of the platform in order to provide a clear idea of the required cut and fill zones. The grading plan should preferably ensure that solution drains to a single spot or the lowest spot of the pad platform at the toe of the heap. An adequate drainage system helps to ensure earthworks optimization by helping engineers accurately design cut and fill zones.

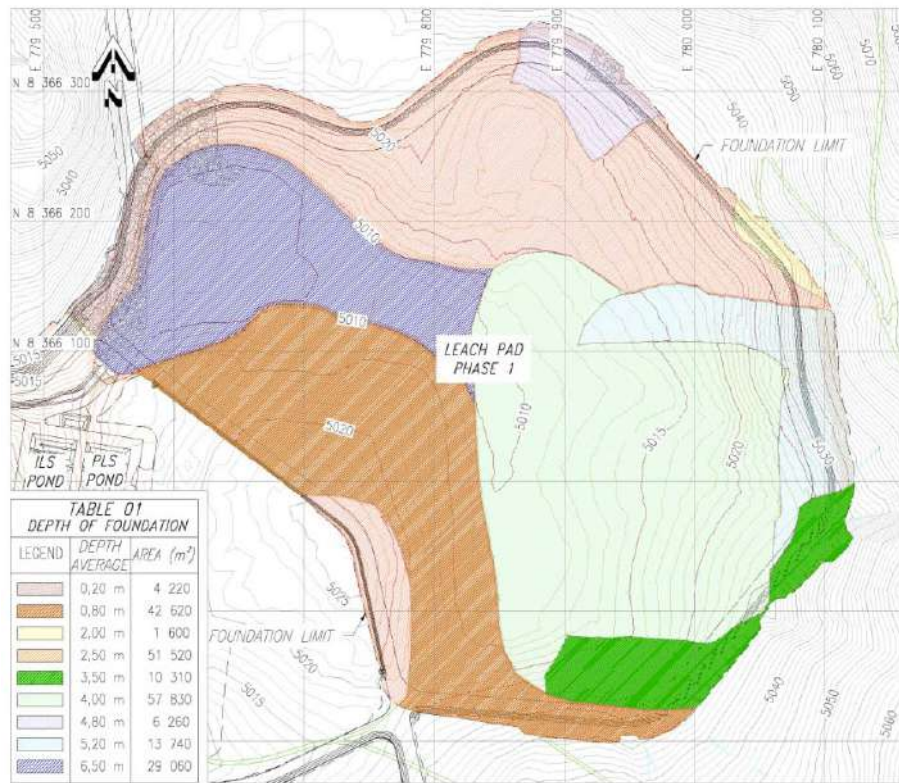


Figure 1: Typical heap leach pad foundation plan

Very steep slopes

Earthworks can also be optimized when the area has very steep slopes, as is common in aggressive terrain. In such cases, extra cuts are made to create a proper slope (usually less than 2.5H:1V or 2H:1V) to make it possible to place and compact low permeability soil (clayey soil).

In these cases, a well-shaped slope is preferable to massive cuts or excavations (Figure 2). This slope will be lined with low permeability soil or GCL, depending on how steep the final slope is, before a geomembrane is put in place. If GCL is placed, then its effect on heap leach pad stability needs to be addressed. A well-shaped slope reduces not only the requirement for earthworks but also the length of the construction schedule.

In most cases, very steep rocky slopes in aggressive terrain must be shaped or graded using blasting. As a consequence, is unlikely to get graded or regular surfaces in theses slopes, as shown in Figure 3. In such cases, irregular surfaces should be improved using shotcrete, mortar, soil-cement, or other products that improve the final grade. Depending on slope irregularity, another way to improve the surface is to use a protection system such as high-weight geotextile, geocomposite (geonet between two geotextile layers), or electro welded wire mesh before GCL and geomembrane installation. These methods reduce rocky surfaces with sharp edges or cavities that can damage the GCL and geomembrane through punctures or

deformation during ore stacking. Figure 4 shows some techniques used for grading irregular slopes and final surfaces for protecting the liner systems.

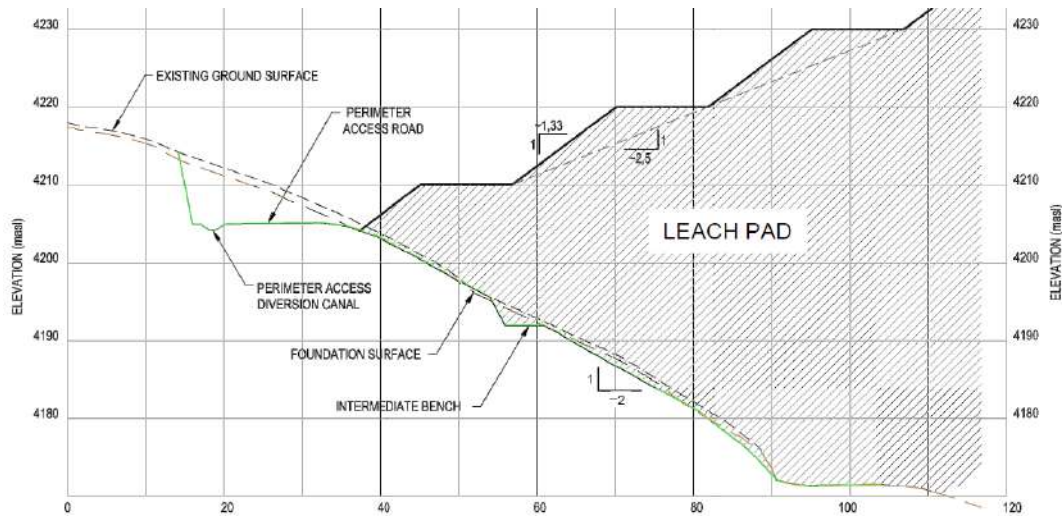


Figure 2: Typical grading (well-shaped slope) on a very steep slope in aggressive terrain



Figure 3: Very steep rocky slope with irregular shape after blasting



Figure 4: Typical grading and protection for geosynthetics installation on very steep slopes

Selection of soil liner or GCL

In deciding whether to use low permeability clayey soil liner or GCL in an area, the following general recommendations should be considered:

- Soil liner can be placed on slopes up to 1.5H:1V, but requires a winch system to pull the roller for compacting on the slope (see Figure 5), as indicated in Currie and Parra (2010). This is done mainly for safety reasons, even in cases where the roller can work on the slope without a winch system.
- Slopes steeper than 1.5H:1V must be lined using GCL.
- In some projects with safety restrictions on the use of winch systems or with untrained staff, soil liner must be placed on slopes lower than 2H:1V or even 2.5H:1V.



Figure 5: Soil liner compaction on a very steep slope

Surfaces with very aggressive terrain and very steep slopes involve additional aspects that should be considered in evaluating whether to use GCL or soil liner. When slopes are very steep – greater than 1.5H:1V or even 2H:1V, in some projects – it can be impossible or very difficult to place and compact low permeability soil (typically 300 mm). Other considerations include optimization of earthworks cost when there are restrictions or difficulties in obtaining soil liner, and reduction of the construction schedule.

Some projects in Peru have been developed where there were considerable restrictions on obtaining soil liner. These restrictions include a lack of available borrow sources close to the project; available borrow sources a long distance from the construction site, which increases hauling costs and, consequently, the overall cost of soil liner placement; available borrow sources, but in wet conditions and a rainy environment, which makes them impractical to use. These restrictions often lead engineers to optimize earthworks with the objective of installing GCL in areas where the slope is not necessarily very steep. Table 1 compares the use of soil liner or GCL for earthworks optimization.

There are several technical aspects that must be taken into consideration when using GCL:

- GCL can be used on steep slopes with a previous verification of heap leach pad stability.
- GCL must not be used in platforms or lower zones in the leach pad because its shear strength is much lower than that of soil liner.
- Reduction of GCL shear strength through hydration must be considered during laboratory testing for shear strength determination. During heap leach pad operation, GCL is likely to be hydrated by solution leakage through the liner system or by underground water, making the shear strength even lower.

Figure 6 shows a typical project drawing for a region where soil liner availability is restricted; the design criteria call for installing GCL as much as possible, including in some areas of the leach pad with slopes lower than 2.5H:1V.

Table 1: Comparing low permeability soil liner and GCL

Low permeability soil liner	GCL
Generally the most economical alternative as long as slope is lower than 2.5H:1V or even 2H:1V and proper borrow sources are available close to the project.	More economical on irregular slopes after blasting and when soil liner is not readily available close to leach pad.
Can be used on slopes up to 1.5H:1V. Restricted in some places to 2H:1V or 2.5H:1V.	Can be used in any slope of leach pad with verification of overall geotechnical stability.
Can be placed directly on subgrade and structural fill, according to the grading design.	In steep rocky slopes with irregular shapes, must be placed in conjunction with geocomposite or geotextile to avoid punctures.
Can be placed on very irregularly shaped subgrades.	Because of length of roll, intermediate benches have to be designed and constructed for anchoring.
Does not require intermediate benches unless solution collection system needs them.	Vulnerable to hydration by phreatic level in foundation, decreasing its efficiency as protection.

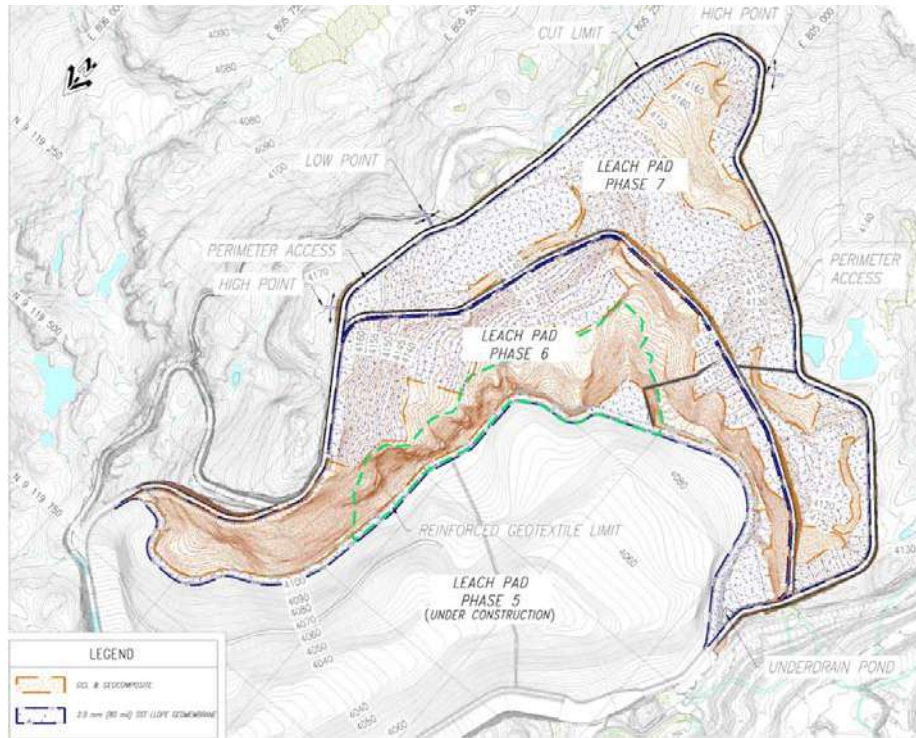


Figure 6: Optimized area for GCL utilization

Pre-cambering in weak foundation or massive fills

Pre-camber design as part of the grading plan can be considered in the following two scenarios:

- When the foundation is very deep in large areas of the leach pad, conventional design encourages removing all unsuitable soil and then backfilling with borrow material up to the final leach pad subgrade; this significantly increases construction costs. In this case, a deformation analysis is needed to estimate both the minimum practical thickness of unsuitable soil to be removed and replaced and the settlement to be expected during heap operation because of the remaining weak soil foundation. Settlement of the still weak foundation is used to configure a pre-camber as part of the grading plan.
- When a large fill platform is needed for proper stability or to increase the area available for first lift stacking, deep fill is needed for the platform and in order to reduce costs. In this case, a massive fill with 0.5 or 1 meter lift is used and compacted with large compaction equipment. As the fill is not structural, settlements (significant in some cases) are expected to occur during ore stacking (by ore weight); these are estimated based on a deformation analysis and used for pre-cambering in the leach pad platform as part of the grading plan.

In both cases, pre-cambering will help to maintain the integrity of the geomembrane and the efficiency of the solution collection system.

A case similar to the first scenario is located southern Peru. Here, there was 20 m of loose granular soil in a large area of the projected leach pad. Deformation analysis indicated that at least 4 m of this unsuitable soil had to be removed and replaced by a 3 m rockfill (as stabilization material) and a 1 m structural fill. At this condition, 0.6 m maximum settlement was calculated through a strain-stress PLAXIS analysis, using maximum heap height; this value was used for configuring pre-camber in the settlement area, with significant savings in capital expenditures (capex). Figure 7 shows a detail of the pre-camber as proposed in the engineering design; rockfill and structural fill are shown along with the final subgrade projection considering the expected settlement.

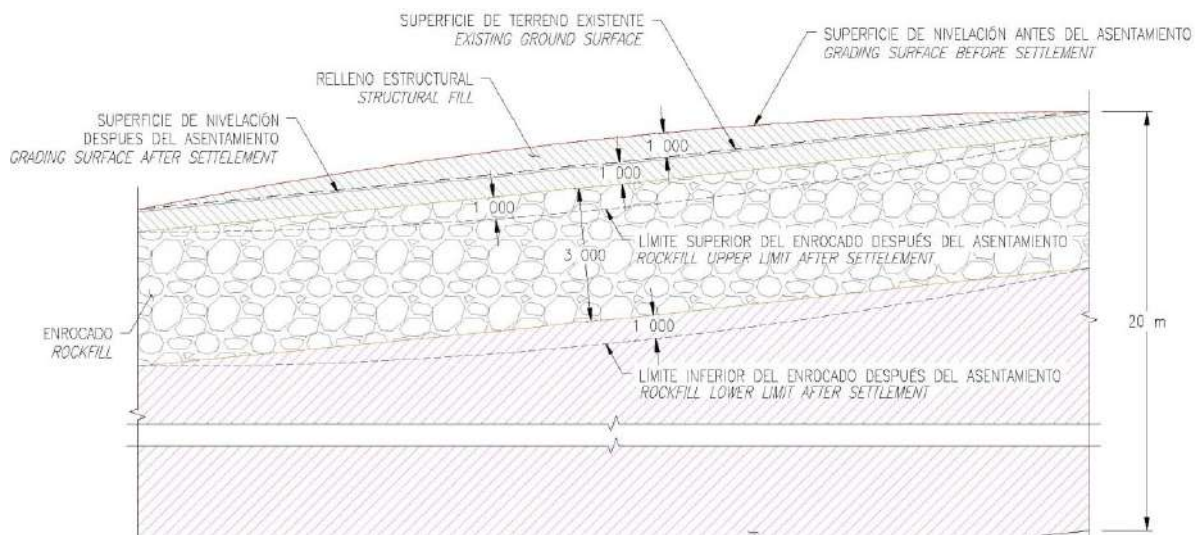


Figure 7: Pre-camber design in a structural fill over weak foundation

Geosynthetics design and installation

Geosynthetic installation in very aggressive terrain needs a proper design, as described below. In areas where the final slope after grading is steeper than 1.5H:1V (or lower in some places), GCL must be installed; the edge will be buried in an anchor trench and the roll deployed along the slope (see Figure 8). In order to protect GCL from punctures on rocky slopes, a protection geocomposite or another protection system must be used. The GCL and geocomposite must be installed in those areas of the leach pad where overall stability is not compromised. These zones will be identified as part of the design process and verified during construction.

Soil liner, GCL, or a zoned combination of both will be placed as a second containment layer on prepared subgrade. The first and main containment will be the geomembrane liner, which will be installed

over the soil liner or GCL. Based on our experience in very aggressive terrain, low linear density polyethylene (LLDPE) geomembrane, single-side textured, is recommended for heap leach pad application. The textured side must be placed in contact with the soil liner or GCL to improve the shear strength of this interface. LLDPE geomembrane shows better performance against punctures and higher interface shear strength when compared with high density polyethylene (HDPE). The optimum thickness of the geomembrane depends on its susceptibility to punctures. However, the following practical rule can be used: use 1.5 mm for heaps up to 100 m and 2.0 mm for higher heaps. If the heap leach pad is very deep, then a geotextile protection is better and cheaper than a thicker geomembrane (2.5 mm).

In very aggressive terrain with very steep slopes, geosynthetics installation is very complex. Because of the deployment of heavy rolls is performed downslope and the geomembrane welding is done many times with the operators hanged on the slope, it is extremely important that the installers are experienced in order to guarantee installation quality and safety. Figure 8 shows complex geosynthetics installation work.



Figure 8: Complex geomembrane and GCL liner installation on very aggressive terrain

Intermediate benches

As noted, because steep slopes cover large areas in many leach pads, intermediate benches are sometimes needed. Figure 9 shows a typical section of an intermediate bench. Bench layout is designed based on a maximum-length GCL roll (typically 45 m); however, when only a soil liner is used, the distance between benches is determined by the maximum length of the geomembrane roll, in order to avoid horizontal seams. Typical roll length is 150 m for 1.5 mm or 120 m for 2 mm geomembrane; however, longer rolls can be ordered before manufacturing to minimize benches. These benches provide the following advantages:

- The leach pad can be designed using a phased construction concept, incorporating as many benches as needed in each phase, depending on the capacity requirements for each phase.

- The solution collection system can be designed independently in each phase, making the system more efficient, with no connection to the previous phase; the solution can be diverted directly to the process ponds.
- Rainwater control is efficient and avoids the entrance of these flows into the heap leach pad, which would dilute the solution and make metal recovery at the plant more complicated and costly.

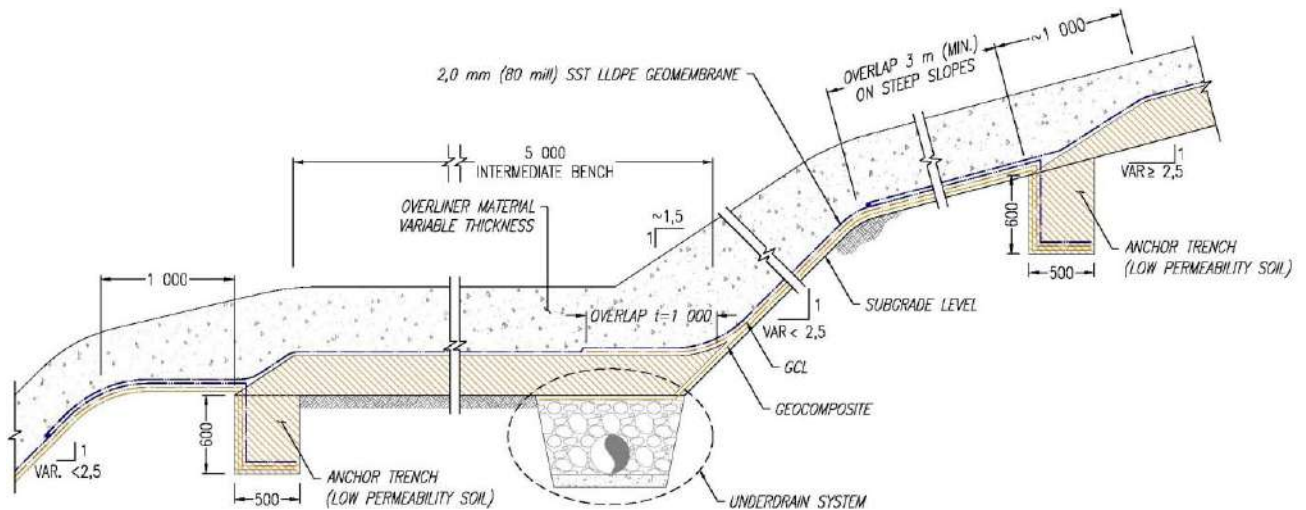


Figure 9: Intermediate bench: geosynthetics anchorage

Solution collection system

Solution collection system design in very aggressive terrain is governed by the following considerations:

- Collection pipes should be placed in areas where slopes are lower than 4H:1V. Installation in slopes steeper than 4H:1V is not necessary because collection will not be efficient.
- Intermediate benches should be used for evacuating solution from subsequent phases directly into the process pond, or even to a process plant if gravity makes this possible. This is a good practice, verified in several mining operations, and results in a more efficient system.

Figure 10 shows a plan view of a solution collection system in very aggressive terrain with intermediate benches.

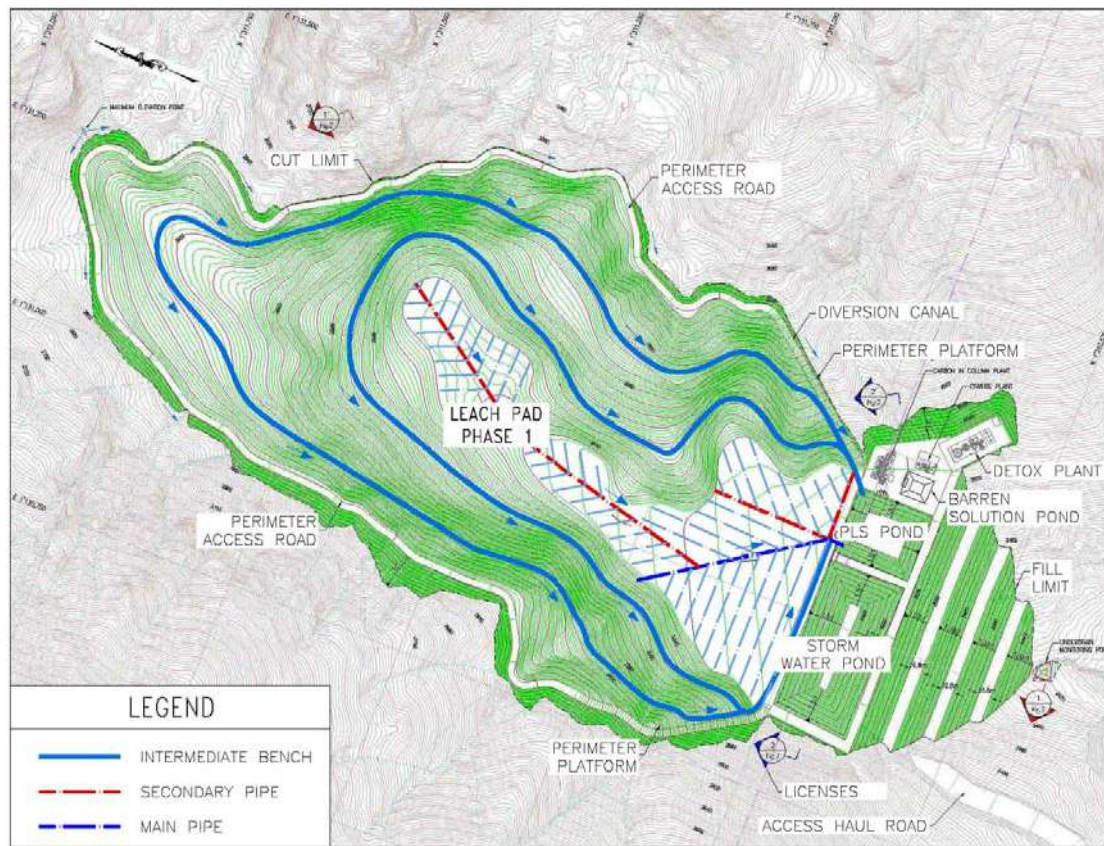


Figure 10: Solution collection system in very aggressive terrain

Issues with first lifts

In valley heap leach pad design, there are generally issues with first lifts associated with narrow valleys. During stacking, it is common to have a mismatch between the capacity (tonnage) and leach area of first lifts for initial irrigation. In this situation, operators usually have three options:

- Restrict ore stacking, and therefore production, based on the area available, and irrigate just the available area.
- Stack two or three lifts to obtain the minimum area for leaching, based on the ore leach cycle, and then start irrigation.
- Combine the two previous options.

In all cases, production will be restricted to the minimum leach area as long as the valley is progressively filled.

Figure 11 shows a view of an ore stacking plan, where problems in the first two lifts are observed; Figure 12 shows a typical section of a valley fill heap leach pad.

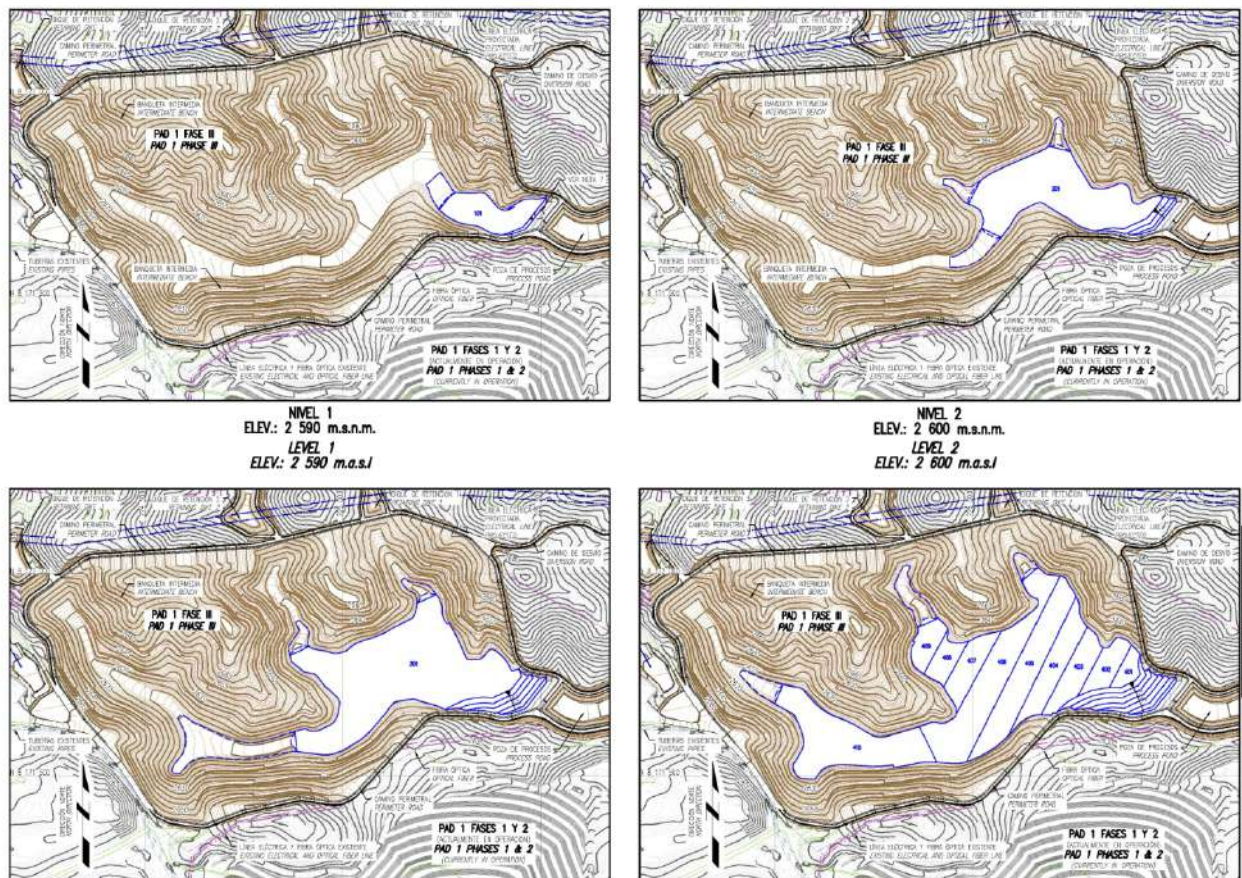


Figure 11: Ore stacking plan in a valley fill heap leach pad

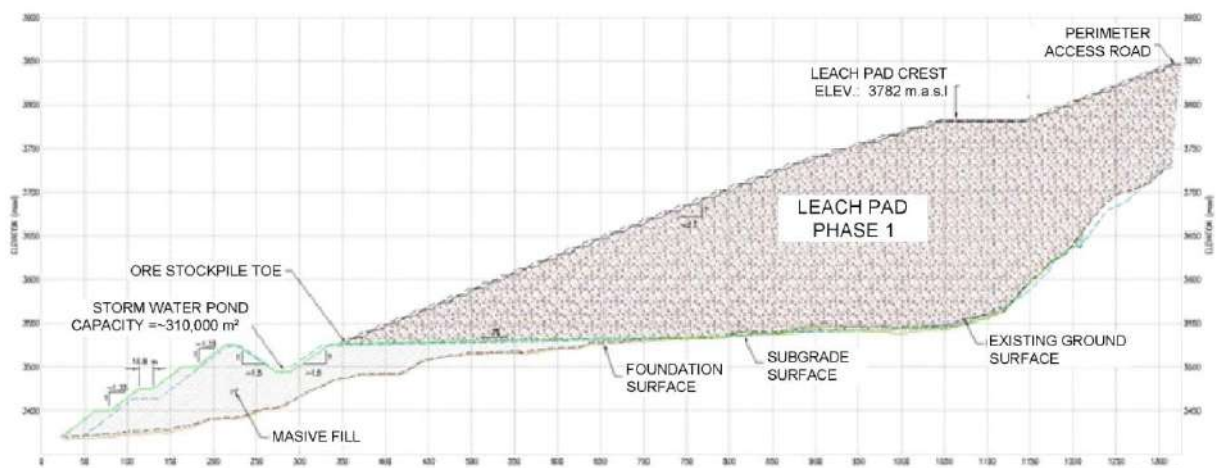


Figure 12: Typical section of a valley fill heap leach pad

Conclusions and recommendations

The following conclusions and recommendations are based on the developed work:

- When low permeability soil liner is not available close to the project or is limited because of high costs for obtaining or preparing the liner, it is important to perform a comparative cost analysis between soil liner and GCL.
- When using GCL is an option for a leach pad project in very aggressive terrain, earthworks optimization should be performed to reduce the overall cost of the project and the construction schedule.
- In areas with weak foundation or massive fills, a pre-camber design becomes very useful for avoiding potential damage to the geomembrane and solution collection pipes.
- GCL should be protected from punctures by geocomposite, geotextile, or another system.
- LLDPE geomembrane, single-side textured, is recommended because of its better performance against punctures and higher interface shear strength compared with HDPE.
- The installer's experience is extremely important for guaranteeing installation quality and proper safety conditions in very aggressive terrain.
- Intermediate benches allow phased construction, independent solution collection systems, and efficient rainwater control.
- Collection pipes should be placed in areas where slopes are lower than 4H:1V.
- In valley fill heap leach pads, there are usually first lift issues associated with valley narrowness and small leach areas. Restrictions on initial metal production must be considered by the mining operation.

References

Currie, S. and Parra, D. (2010) Leach pad design and construction issues in very steep slopes. In *Proceedings of the 9th international Conference on Geosynthetics, 9ICG*, May 2010, Guarujá, Brazil.