DRAINAGE NET FOR IMPROVED SERVICE AND COST REDUCTION IN HEAP LEACHING[1]

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Heap leaching is a mineral processing technology whereby large piles of crushed or run-of-mine rock (or occasionally mill tailings) are leached with various chemical solutions that extract valuable minerals. The largest installations in terms of both land area and annual tonnage are associated with copper mines, where copper-containing minerals are irrigated with a weak sulfuric acid solution. This solution dissolves the copper from the mineral and the "pregnant leach solution" (PLS) passes down through the ore pile and is recovered at the bottom on the "leach pad," which usually consists of a geomembrane liner, sometimes clay (either to create a true composite liner or more commonly simply as a good quality bedding layer for the geomembrane), and a permeable crushed rock "overliner" with a drainage pipe network. In some applications (principally oxide copper ores) thin liners are installed between layers or "lifts" of ore to intercept the PLS earlier. Copper is extracted from the PLS using electrowinning processes and the acidic solution is recycled back onto the leach pile. Gold heap leaching is similar, except that the solvent is an alkaline cyanide solution.[4]

Leach pads can be divided into four categories: conventional or "flat" pads, dump leach pads, valley fills and dynamic pads. Conventional leach pads are relatively flat, either graded smooth or terrain-contouring on gentle alluvial fans and the ore is usually crushed and stacked in relatively thin lifts (5 to 15 m typically). Dump leach systems are similar or can include rolling terrain; the term "dump" usually means that the lifts are much thicker (up to 50m) and frequently the ore is not crushed (run of mine). Valley fill systems are just that – leach "pads" designed in natural valleys using either a buttress dam at the bottom of the valley, or a leveling fill within the valley. For these three types of leach pads the ore is stacked, leached and then another layer is stacked over the spent ore ("ripios"). Ultimate heap heights range from 50 to 135m ($\gamma_{dry} \approx$ 1,450 to 1,750 kg/m^3).

Dynamic pads, or on-off pads, receive a single layer of ore typically 4 to 8 m thick. This layer is leached for a prescribed period, rinsed, and the ripios is then unloaded for disposal. The leach pad is then recharged with a fresh batch of ore and the cycle repeated. Leach cycles range from 2 to 12 months and service lives can exceed 20 years.

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[4] Thiel, R. and M. E. Smith, "State of the Practice Review: Heap Leach Pad Design Issues," presented at the bi-annual meeting of the Geosynthetics Research Institute, in Las Vegas, Nevada, USA, December 2003 and published in the conference proceedings.

Typical Leach Pad Liner Systems

The most common liner system is a single geomembrane on either prepared subgrade or a thin clay composite section (typically 200 to 300 mm of clay). Most leach pads use 1.5 mm HDPE or LLDPE, though deep valley fills will use up to 2.5 mm HDPE or LLDPE and 1.0 mm PVC is a common alternative for conventional pads.

Since heap leach facilities use an active leach system, irrigating the ore to recover the metals, heap drainage is critical to stability, leakage control and metal recovery. The drainage system usually doubles as the liner protection layer, and this combined system (often called the "overliner") usually consists of 300 to 1,500 mm of crushed stone (25 to 40 mm are common maximum particle sizes) with perforated drainage pipes at close spacing (2 to 10 m). Geosynthetic drainage layers are occasionally used, principally for valley fill applications on the steep canyon slopes where gravel placement is difficult and risky.

Dynamic heaps tend to use more robust liner systems and thicker overliners, sometimes composed of two layers to create a relatively thick "heel". This heel serves the additional function of protecting the liner and drainage system from the repeated loading of the stacking and unloading equipment. The most common application would include a heel of 1,000 to 1,500 mm including an open graded drainage layer of -25 to -40 mm directly on the geomembrane, and covered with a protective operations layer of coarse crushed waste rock or metal-bearing ore, with maximum particle sizes ranged from 100 to 200 mm. The drainage pipes would be directly on the geomembrane and within the bottom layer.

Summary of Synthetic Drainage Technology

The liquid drainage layer at the base of heap leach pads need to fulfill the following requirements:

- to have sufficiently high inflow permeability to allow uninhibited flow from the adjacent fill material;
- to maintain sufficient in-plane flow capacity to limit the hydraulic head over the liner;
- to withstand short- and long-term compressive loads; and
- to provide adequate shear stability.

During the evaluation and selection process of potential drainage layers, a design engineer typically may consider two options: natural materials or geosynthetic drainage products. The advantage of natural material is its familiarity to the geotechnical engineers and the shear thickness of the cross section. However, the use of natural material creates constructability and quality assurance concerns, including: side slope stability, geomembrane damage, installation scheduling and sequencing, and consistency and quality of the type and depth of the fill. There are many advantages for drainage geocomposites. For instance, ease of installation on slopes, consistency in material properties inherent with manufacture materials, and in many cases, there are also cost savings.

There are two common types of drainage geonets, based on their structures: bi-planar and tri-planar. Bi-planar geonets, as the name implies, consist of two layers of strands superimposed over each other; Tri-planar geonet consist of two layers of strands separated by thick vertical ribs, creating a wide flow channel. Photo 1 shows photos of these two types of geonets.

The development of drainage geonets has been aimed at achieving higher in-plane flow capacity (transmissivity) and reducing the long-term compressibility of the geonet structure. Bi-planar geonets have certain limitations due to their structures. For example, increasing the thickness of the ribs may lead to an unstable structure with low rollover compression strength; and increasing the in-planar porosity by enlarging the rib spacing leads to greater intrusion of geotextiles into the geonet core. The tri-planar geonet, however, eliminates the limitations of the bi-planar geonet. The primary flow plane of the geonet is located between the top and bottom secondary flow planes. The top and bottom auxiliary flow planes accommodate intrusion of geotextiles used with the geonet for filtration or protection functions. Photo 2 provides a close look at the tri-planar structure.

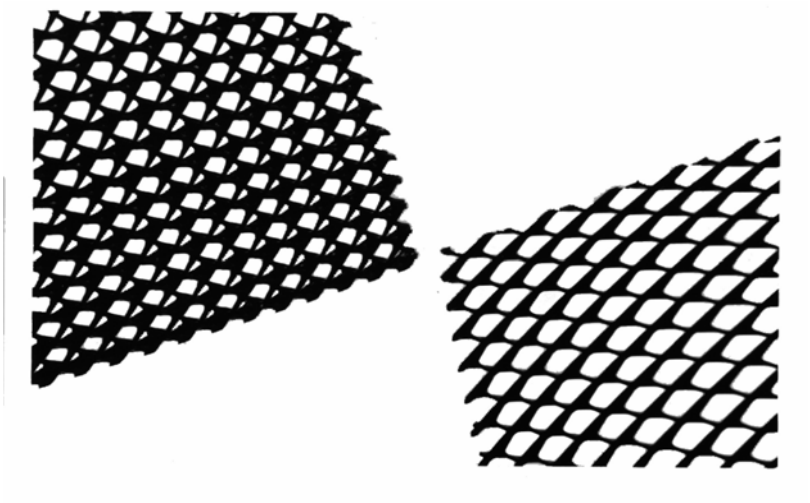

Photo 1. Photos of different types of geonet drainage products.
(Left: tri-planar, Right: bi-planar)

The tri-planar geonet incorporates vertical middle ribs constructed to be stronger than the inclined ribs of the bi-planar geonets. The comparison of compressive strength of a tri-planar geonet to bi-planar geonets is shown in Figure 1. The structure of the tri-planar geonet remains stable even under very high normal pressure with no inflection point, while most bi-planar geonets can crush or rollover between 600 to 800 *kPa*. To address concerns about the structural stability of a geonet product under sustained large normal load, Holtz, Christopher and Berg (1997)[5] recommend the design load on a geonet be

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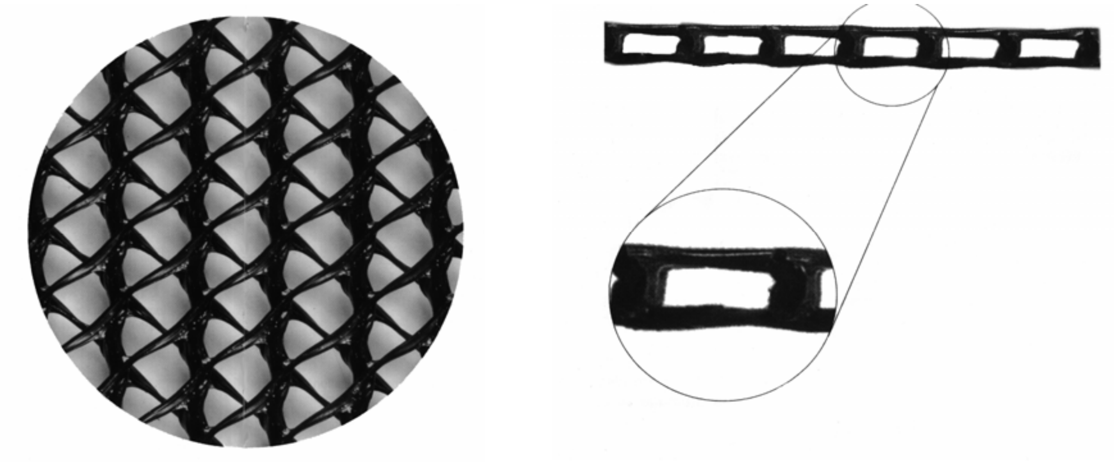
[5] Holtz, R., Christopher, B. and Berg, R. (1997), Geosynthetic Engineering, BiTech Publisher, Canada

limited to either (a) the maximum pressure sustained on the core in a test of 10,000 hour minimum duration; or (b) the crushing pressure of a core as defined with a quick loading test, divided by a safety fact of 5. Compressive strength of 800 kpa as shown in Figure 1 would be equivalent to only 9 m of heap depth (ignoring the weight of the stacking and other equipment) assuming an average density of 1,700 kg/m^3 and safety factor of 5 for load. A bi-planar geonet with such a low compressive strength is thus technically not suitable as a drainage medium under most leach pads.



(a) (b)

Photo. 2 Structure of tri-planar geonet (a) plane view, (b) cross-section.

Figure 2 presents the in-soil transmissivity of a tri-planar geocomposite measured under different normal loads and hydraulic gradients. Transmissivity decreases with increasing normal loads and increases with decreasing flow gradients. The tri-planar geocomposite's in-soil flow capacity far exceeds other geocomposites, especially under heavy normal loads. On a leach, pad higher in-plane flow capacity results in fewer drainage pipes and a thinner heel layer, as well as a lower hydraulic head over the liner. Given the size of typical leach pads, this can result in significant reductions in pipe and gravel.

For a geonet to effectively function as a lateral drainage layer, the geotextile filter component of the geocomposite should be properly designed to prevent excessive clogging or excessive lose of fines from the leached ore, Empirical equations are available to evaluate clogging potential. In addition, gradient ratio test can also be used to assist in the evaluation of a geotextile clogging potential with respect to a specific fill material[6].

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[6] ASTM D5101, Standard test method for measuring the soil-geotextile system clogging potential by the gradient ratio.

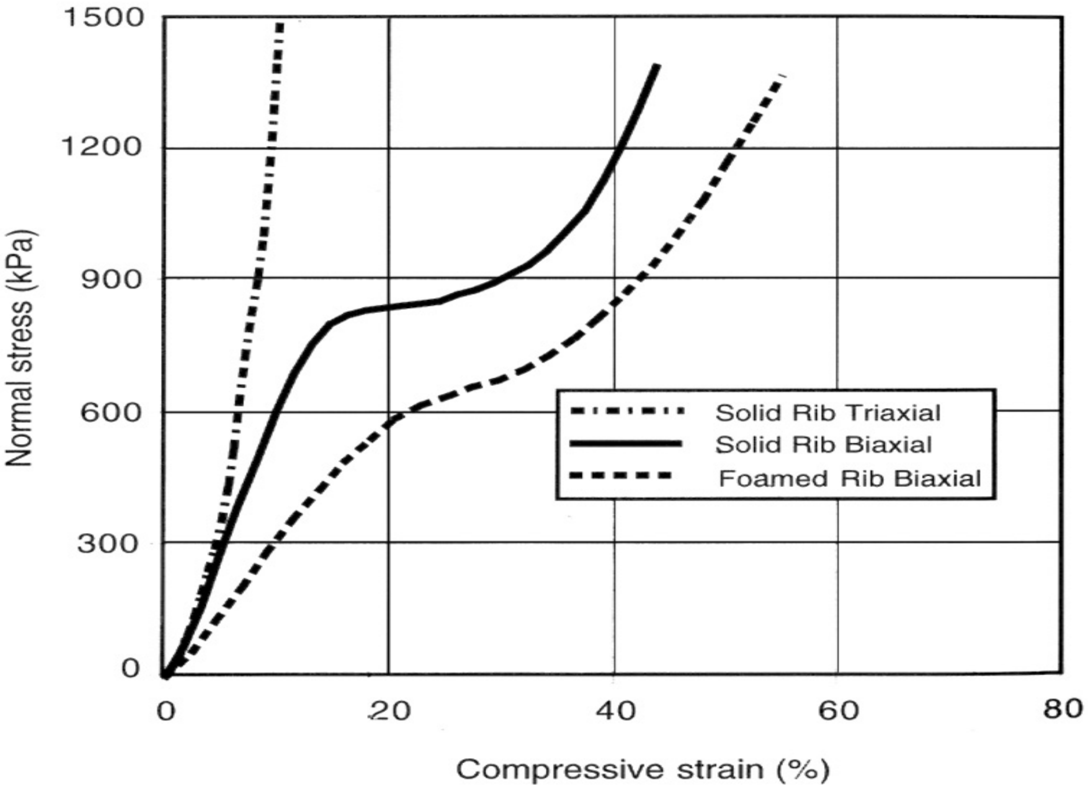

Figure 1. Compressive test data of different geonets (after Koerner, 1998)[7]

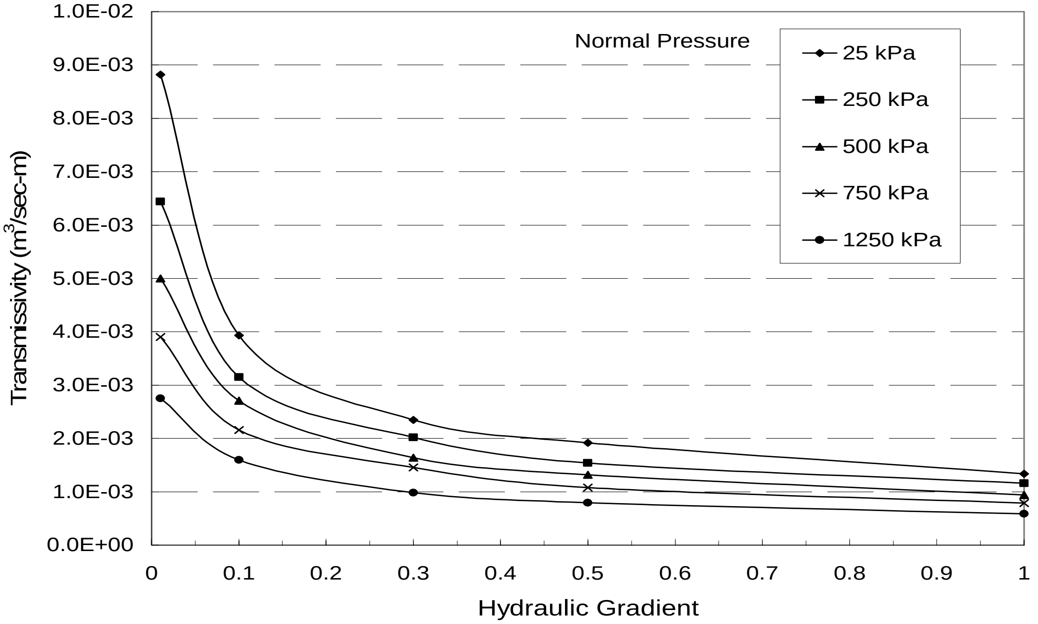

Figure 2. In-soil transmissvity test results – tri-planar geocomposite

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[7] Koerner, R.M. 1998, Designing with Geosynthetics, Prentice-Hall, New Jersey.

Project Description

A modest sized copper heap leach facility is planned for a site in the Amazon. A dynamic heap was considered due to climate factors (minimizing the area collecting rainfall) and metallurgical factors. The base case design was a 2.0 mm LLDPE liner with a two-layer "heel" system (drainage plus operations layer) consisting of 500 mm of minus 40 mm crushed rock and 1,000 mm of minus 100 mm crushed rock. The leach pad dimensions were approximately 540 m by 1,200 m, or about 650,000 square meters in total area. The ore would be transported to the side of the leach pad on an overland conveyor feeding a tripper and bridge conveyor and a series of "grass hopper" conveyors across the pad. Stacking would be via a radial stacker working on top of the heal layer. Unloading would use front end loaders (CAT 988 or 992 class) and mine haul trucks (180 tonne class). Truck and loader wheel loads, especially while turning or braking, create the structural design load for the geomembrane and pipes, as opposed to the static weight of the heap which is the typical design load for a conventional pad.

Photo 3: Access to the site showing the saprolitic soils and dense vegetation common to Amazonian sites.

An Alternative Approach

Local sources of hard rock were available, principally resulting from mine waste generation and the volume of material needed was large enough to give relatively good economies of scale. However, a critical factor at high rainfall sites is the short "dry" season during which most construction must be completed. It can rain nearly every day of the year in the Amazon, and the volume of crushed stone needed would require about 3 months to produce, consuming essentially the entire dry season and leaving little margin for scheduling error. Thus, some of the gravel would need to be produced in the wet season, carrying a price premium as well as operating problems such as access, erosion and silt control. These limitations brought to consideration alterative ways to build the heel and a combination of a reduced gravel section plus a geocomposite drainage net was considered. Table 1 summarizes the comparative calculations for this technical and cost trade-off study.

Photo 4: Aerial view of the site and the Amazon basin.

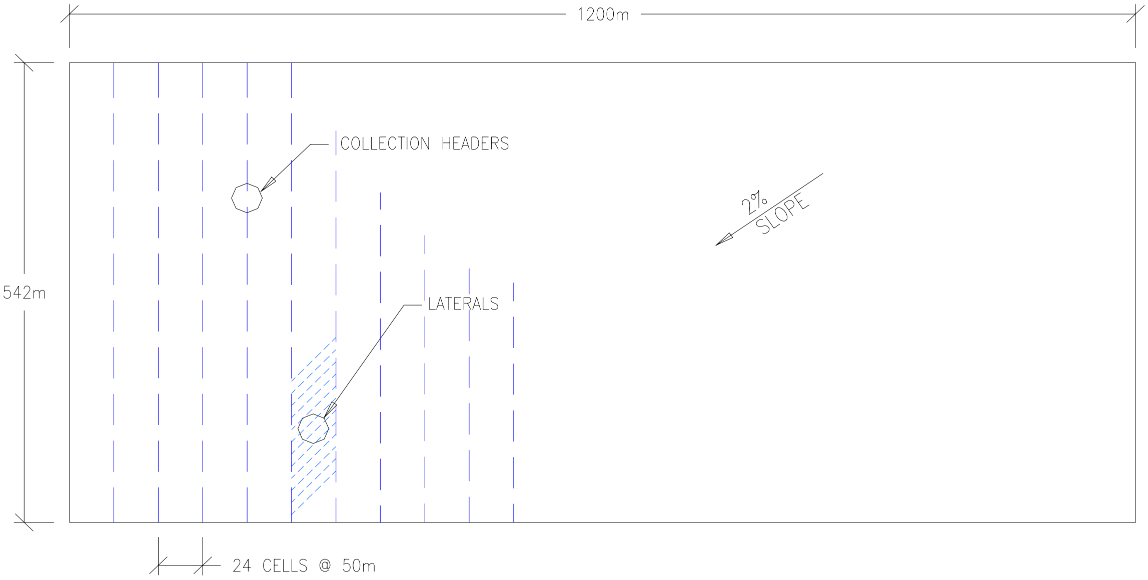

Figure 3: Plan view of leach pad

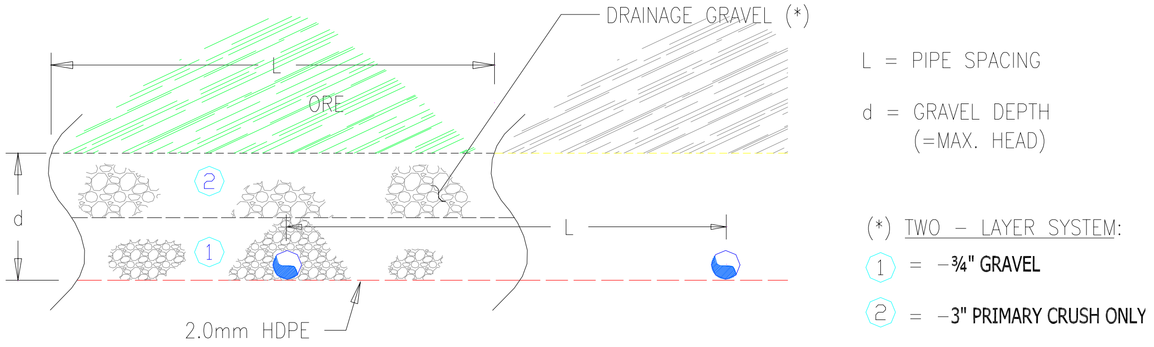

Figure 4: Conventional Drainage System Showing “Heel”

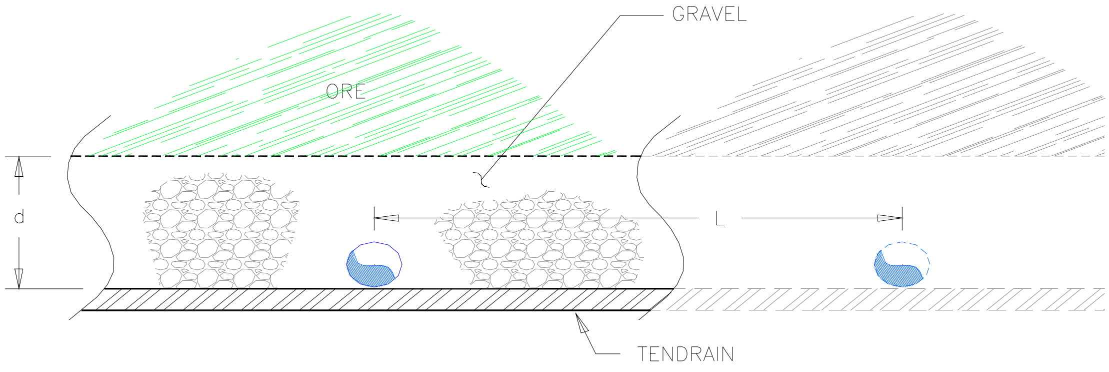

Figure 5: Drainage layer using tri-planer geonet and reduced heel

Table 1: Summary of analyses of conventional & geonet options

<table>
<tr><th>Conventional Gravel & Pipe System</th><th>Geocomposite & Pipe System</th></tr>
<tr><td colspan="2">Design Criteria:
(a) Irrigation rate: 9l/hour/m^3 average process rate, 15 l/hr/m^2 peak with allowance for rainfall
(b) Gravel permeability, $k = 5 \times 10^{-3}$ cm/sec
(c) Geocomposite transmissivity, $T = 3.85 * 10^{-3}$ m^2/sec
(d) Maximum heap height, h = 10 meters</td></tr>
<tr><td colspan="2">Find: (a) Pipe spacing for maximum 1.0 meter hydraulic head over liner;
(b) Pipe diameter (using corrugated dual wall/smooth bore PE pipe); and,
(c) Depth of gravel (equal to maximum hydraulic head, 1.0 m or less set by environmental controls and industry convention).</td></tr>
<tr><td>Solution:
See Figures 3 & 4 for the plan view and cross-section of the leach pad.
Pipe spacing, L = 7 meters ; from elliptical drainage equation: $h_{max} = (L^2 \times r / 4K)^{0.5}$
Pipe diameter = 3 inch nominal (for 50% flow)
Maximum head = 1.0 meters
Depth of gravel required = 1.0 meters as follows:
500 mm of -3/4 inch crushed and screened waste rock, fines free
500 mm of primary crushed waste rock</td><td>Solution:
See Figures 3 & 5 for the plan view and cross sections of the leach pad.
Capacity of geonet to transmit flow to lateral pipes (use Tendrain 5100-2 by Tenax)
$Q_{tendrain}$/unit width = (i) x (T) = (.02) x 3.85x10-3 m^2/s
$Q_{tendrain}$/unit width = 0.28 m^3/hr/m-width
Q_{actual} = 0.075 m^3/hr/m-width
FOS for lateral flow = 0.28 / 0.075 = 3.7
Therefore, gravel is not needed for hydraulic head control, only for puncture protection.
Maximum head = thickness of geonet << 1.0 m
Check pipe diameter:
Q_{pipe} = (15/1,000) x 71m x 10m = 10.65 m^3/hr
Required pipe size = 4 inch nominal (50% full)
Depth of gravel required – controlled by protection of geomembrane only:
Minimum constructible thickness over geonet = 300 mm</td></tr>
<tr><td>**$5,586,000 or $8.60/m^2**</td><td>**$5,372,000 or $8.30/m^2**</td></tr>
</table>

Applicability to other heap leach operations

The costs used for this example are typical for many South American projects. Local availability of good, durable and chemically resistant rock varies from site to site; In some cases such material is simply not available. Further, the case study considered here was for a site in a country with some of the highest import tariffs in South America. All other factors being equal, the geonet option for a site in Chile (for example) will have even more favorable economics.

Table 2 summarizes some of the recent heap leach projects in Latin America, showing the magnitude of the projects under consideration. Given local constraints on logistics, movement of personnel and materials, site access, plant production capacity and installation crew availability, peak installation rates at any given site range from 0.5 to 1.0 ha/day. Thus, construction periods for installing the geomembrane, before consideration of earthworks, heel placement, and other construction components, require up to one year and average 4 to 6 months. The typical depth of the drainage and operations layer for leach pads using a conventional aggregate design is about 300 to 500 mm for conventional pads and 1,000 mm for on/off pads. Thus, the typical leach pad requires 500,000 cubic meters of crushed and screened gravel, or about 100 to 200 days of production, haulage and placement. This overlaps the geomembrane installation, frequently beginning well in advance of liner deployment and usually continuing after "black out." Thus, liner plus heel construction can take most of a year at a larger project, and 6 months even for a modest pad. For sites with complex earthworks, such as a valley fill project, several months may be required in advance of start of liner deployment.

Many of these projects are in the high Andes or the tropics, where the allowable construction season can be as short as 3 to 5 months. Thus, designs that reduce construction time requirements have the additional benefit of lowered risk of delays and reduced costs for construction of the components that would otherwise require installation in the "off" season.

Table 2: Planned & Recently Constructed Leach Pads in Latin America[8]

Location	Type	Pad Area ha	Base Liner	Ore Depth m
Argentina	Valley Fill	150	100 & 80 mil HDPE	130
Brazil	Conventional	119	80 mil HD or LLDPE	75
Chile	On/off	152	80 mil HDPE	10
	On/off	135	80 mil HDPE	10
	On/off	100	80 mil HDPE	10
	Dump	95	60 mil HDPE	110
	Dump	125	60 mil HDPE	125
	Conventional	200	80 mil LLDPE	145
	Conventional	130	30 & 40 mil PVC	75
Costa Rica	Conventional	15	60 mil HDPE	50
Peru	On/off	15	80 mil HDPE	10
	Valley	55	60 mil HDPE	85
	Valley	125	100 & 80 mil HDPE	135
	Valley	75	80 & 100 mil LLDPE	230*

(*) New "base" liner & drain system to be constructed at mid-heap height.

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[8] Thiel, R. and M.E. Smith, State of the Practice Review of Heap Leach Pad Design Issues, proceedings of the bi-annual meeting of the Geosynthetics Research Institute, Las Vegas, Nevada, USA, December 2003.

It is important to note that the use of a geocomposite drainage layer would likely require the use of textured polyethylene geomembrane around the perimeter in the stability zone to preserve the geocomposite/geomembrane interface shear strength. This interface, as well as the internal geotextile-geonet interface on the geocomposite itself, would need to be assessed in the site-specific context of static and dynamic slope stability needs.

The gravel layer directly on top of the drainage geocomposite is for the protection of the underlying geomembrane. A field test pad may be necessary to ensure the gravel layer will not cause damage to the geotextile filter.

Concluding remarks

The tri-planar geonet composite is technically suitable to replace part of the drainage gravel. The geonet drainage alternative has the advantage of dramatically reducing the head acting on the geomembrane liner. A conventional gravel drain will have a 1 m head compared to a 7 mm head for the geonet design. Assuming equal defect size and frequency, the use of a geonet in the drainage system will reduce potential leakage rate by a factor of $(1.0/0.007)^{0.9} = 87$. In addition, geonet provides better puncture protection for routine damage, and reduces risk of construction-related damage (like dozer tearing of plastic) since there is only one layer to place over the liner and it is separated by the geocomposite (a geonet core laminated with two 250 g/m2 nonwoven geotextiles in this case). Since this type of damage creates by far the greatest potential for serious leakage and environmental damage, this reduced risk is a huge benefit. Furthermore, the maximum allowable pipe spacing is 10 m per conventional HL practice based on metallurgical factors, which produces a “hidden” factor of safety by providing more piping than otherwise needed.

The geocomposite alternative design also resulted in about $200,000 savings for a 65 hectare pad. in estimated drainage/cover layer cost.