

Design and construction review of a heap leach pad for safe operation

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Abstract

This paper presents a design and construction review of a heap leach pad located in northern Peru, based on several aspects of interest that have been observed and should be taken into account in future heap leach pad projects.

The review consisted of compiling engineering design and construction (quality dossier) information, focusing mainly on data related to soil liner characteristics and the interface with the leach pad geomembrane. This review was complemented with field and laboratory investigations. Available information indicated a high variability of soil liner in the borrow source area, corresponding with low shear strength silty soils. Moreover, there was a significant difference between the basic properties assumed in the design of the soil liner and the results of the quality dossier, which were similar to those obtained in additional tests performed as part of this review. Likewise, large-scale direct shear testing of the interface between the soil liner and the geomembrane in samples of both materials obtained in the field showed significant differences, with lower interface shear strength than that assumed in the design phase.

During the design phase, a generally stable heap leach pad condition was observed, but with pseudo-static factors of safety below 1, and with limited seismically-induced permanent deformation under the Makdisi and Seed (1977) criterion. On the other hand, stability analysis performed with shear strength parameters obtained by testing *in situ* conditions indicated unstable conditions of the heap leach pad, with relatively low static factors of safety and pseudo-static factors of safety also below 1, but with seismically-induced displacement at greater than permissible values under both the Makdisi and Seed (1977) and Bray and Travasarou (2007) criteria; this led to the design of a toe buttress to obtain long-term stable conditions.

It is necessary to perform a design review after construction, or even better, during construction, in order to verify, update, modify, or improve the original design, as needed. This review must be a mandatory process performed as part of mining operation start up, in order to avoid future heap leach pad instability problems, which may lead to environmental consequences (geomembrane failure), where remediation can be expensive.

Introduction

Nowadays, mining companies in Peru are required by the national mining authorities to perform a detailed design review of their mining-related structures in the country in order to safeguard the environment from any further instability problems that may have not been forecasted during the construction or design phases due to bad practices.

The authors of this paper were involved in reviewing such a project: the design of a heap leach pad that is currently under operation. A plant view of this facility is shown in Figure 1. The review work consisted mainly of analyzing soil liner properties during the design and construction phases.

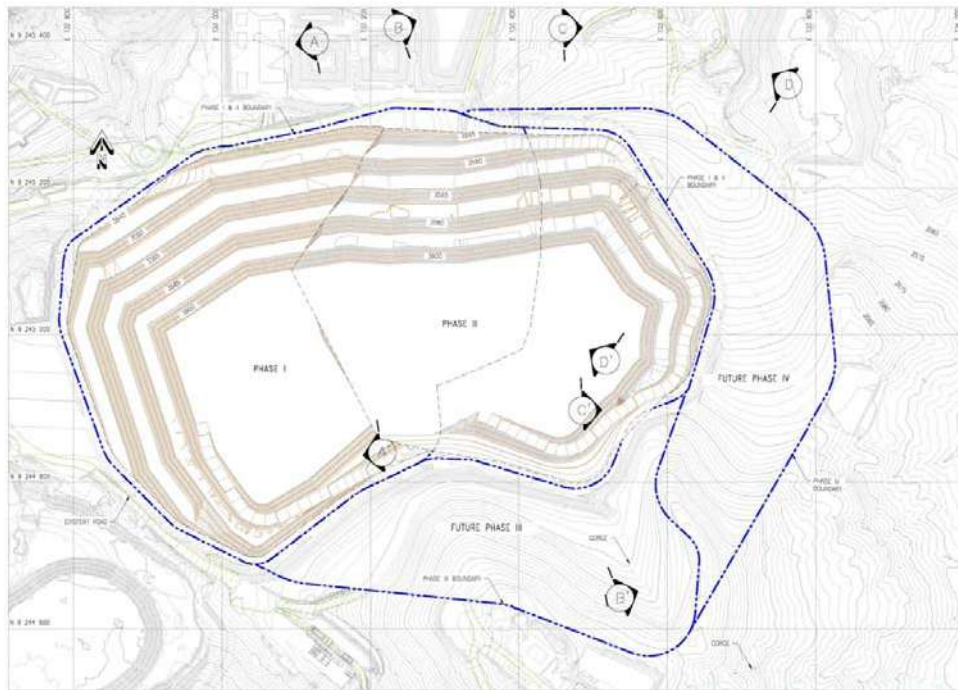


Figure 1: Plant layout of analyzed leach pad, Phases I and II

Soil liner properties were the main scope of the present paper since, in most leach pad projects around the world, interface characteristics are among the most important geotechnical constraints related to leach pad design. In this particular case, the interface consisted of a soil liner and single-sided textured geomembrane.

Construction phase data was obtained from a quality dossier provided by the mining company during the design review phase. The quality dossier conveyed laboratory information such as soil particle size and classification, plasticity index, liquid limit, standard Proctor dry densities, and the results of field tests, such as nuclear gage or sand cone tests for compaction verification. Additional data relating to distances between compaction control field tests and standard Proctor sample points was generated from the quality dossier in order to have an idea of the accuracy and frequency of compaction control.

Construction quality problems

The soil liner was sampled during the geotechnical investigation for revision of the leach pad design. One of the main issues observed during sampling was the soil liner's USCS classification (Unified Soil Classification System) which was mainly a low plasticity silt with sand (ML). This is generally not a proper material for soil liners, since it is likely to offer low interface strength. Another issue tackled during the geotechnical investigation was a comparison between the standard Proctor tests and density measured in the field, based on undisturbed soil liner sampling (shown in Figure 2) and testing.



Figure 2: Extraction of undisturbed soil liner sample for *in situ* block density and large direct shear testing on textured geomembrane and soil liner interface

Several large-scale direct shear (LSDS) tests were performed on textured geomembrane and soil liner interfaces on disturbed and undisturbed samples. These test results were compared to provide further insights on the differences in strength between the *in situ* and laboratory conditions for this kind of man-made soil material. It should be noted that these disturbed samples tested at 95% of standard Proctor density.

As shown in Figure 3, the tests performed on disturbed and undisturbed samples in this study show very low variability compared to tests performed by the designer, which are shown in Figure 4. Figure 3 shows a similar quality of strength across all soil liner tests from samples taken during the geotechnical investigation of the design review phase. Meanwhile, Figure 4 shows some randomness in interface strength over time, not only during the design phase, but mainly during the construction phase. In Figure 4, the strength differences between the design and design review envelopes are very clear; further research that may confirm this huge difference in behavior may account for future problems in leach pad slope stability.

The dossier data obtained at the leach pad was analyzed and compared to the initial data obtained at the design and design review phases. The outcome of this comparison was a huge variability in soil properties during construction time. Figure 5 shows differences of fines content during construction time; the soil liner may vary from silt to sandy or gravelly silt, depending on the gravel and sand content. Figure 6 shows the effect of this variability on standard Proctor points; many problems in controlling material used as soil liner during construction may be due to the high variability of the material obtained from the borrow area.

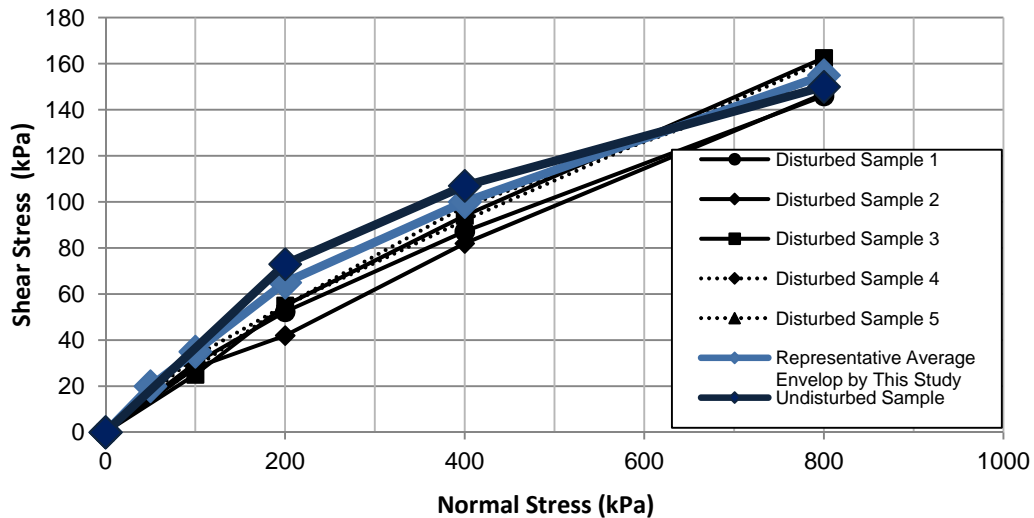


Figure 3: Soil liner shear strength interface envelopes by LSDS in this study

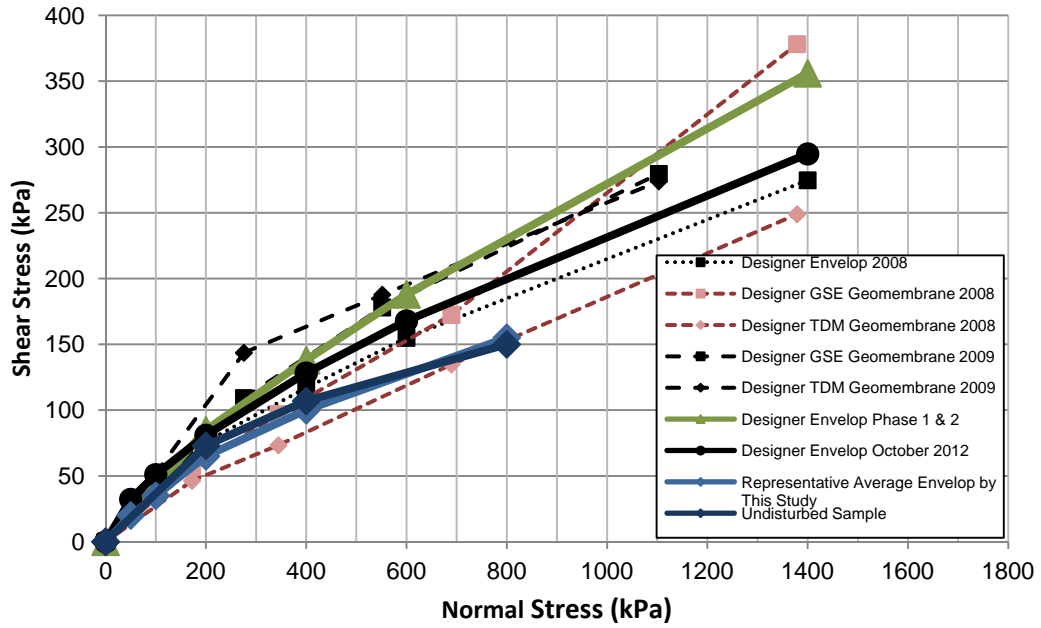


Figure 4: Soil liner shear strength interface envelopes by LSDS by designer. Green envelope was used for leach pad slope stability analysis during design phase

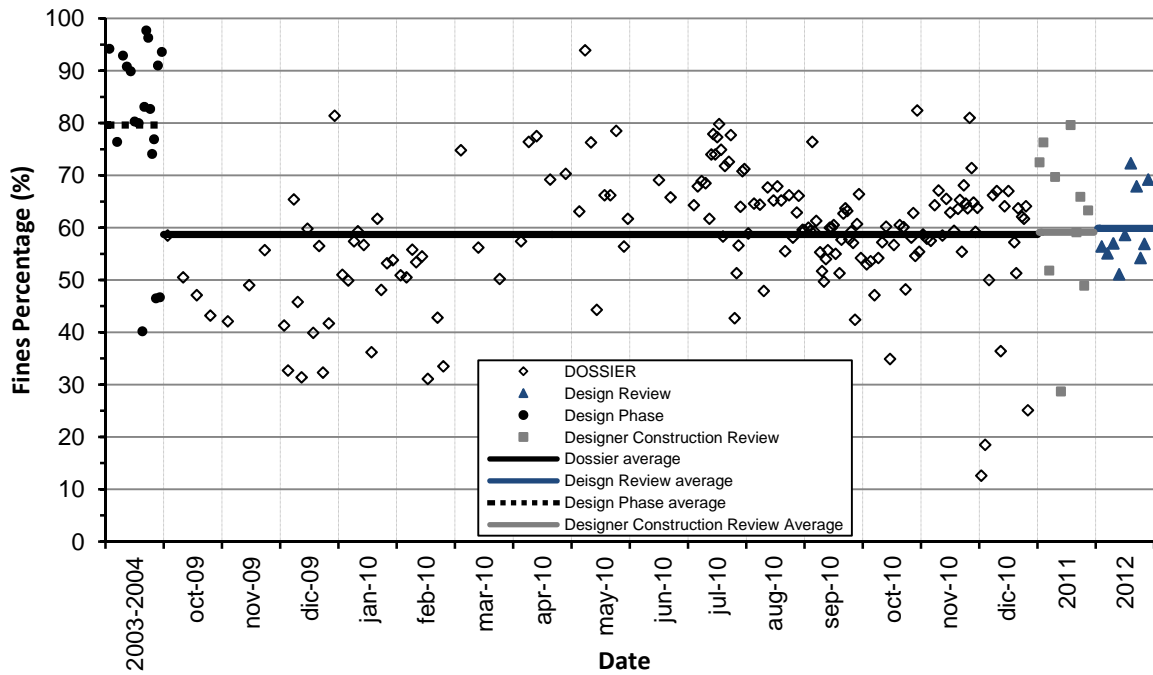


Figure 5: Fines content variation during construction

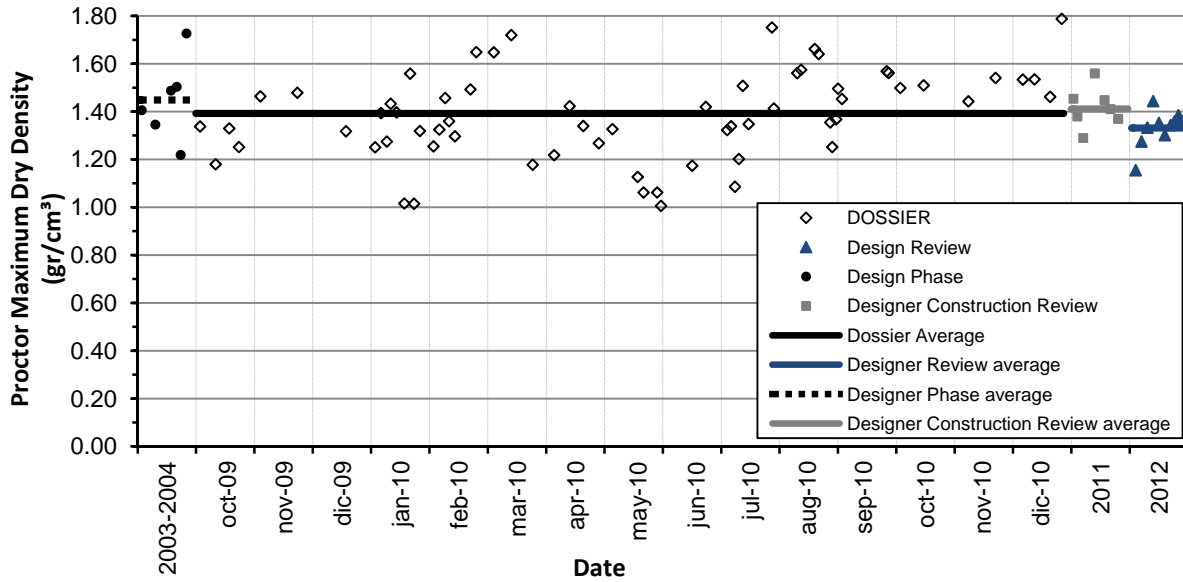


Figure 6: Standard Proctor maximum dry density variation during construction

Finally, another problem that arose while analyzing the dossier data was the distance between standard Proctor control sample points and the compaction control field test points, as shown in Figure 7. The average distance between control sample points and density field tests was about 180 m, which is an unacceptable distance from the laboratory control sample. Construction quality control (CQC) manuals in the industry recommend, at most, 250 to 500 m³ for performing field density tests, and 1,000 to 1,500 m³ for performing laboratory standard Proctor tests, which means a radio distance of around 30 to 40 m between the control sample and the field density test for a soil liner layer of 0.30 m. Since most soil liners are cast over rectangular cell shapes in the field, a maximum average distance of 150 m can be considered for shapes of 20 m in width.

Table 1: Results of stability analysis of leach pad, design phase

Cross section	Static factor of safety	Yield acceleration (g)	Makdisi and Seed (1977) permanent deformation (cm)
A-A	1.30	0.080	30
B-B	1.33	0.088	25
C-C	1.38	0.085	25
D-D	1.55	0.110	20

Table 2: Results of stability analysis of leach pad, design review phase

Cross section	Static factor of safety	Yield acceleration (g)	Makdisi and Seed (1977) permanent deformation (cm)	Bray and Travasarou (2007) permanent deformation (cm)
A-A	1.31	0.082	40	53
B-B	1.29	0.072	54	65
C-C	1.48	0.123	14	31
D-D	1.45	0.113	20	36

As shown in Table 2, leach pad stability is endangered under permanent deformation as calculated by the Bray and Travasarou (2007) method, which is one of the most documented and studied updates of the Makdisi and Seed (1977) method, according to Bray (2007).

For static conditions, it is common in the industry to use a factor of safety of 1.5 in highly seismic regions such Peru; however, the designer chose a minimum static factor of safety of 1.3. Furthermore, this factor of safety was not met in two cross sections analyzed, which indicates not only a long-term seismic-related instability, but also a probable instability during the operation.

Results of factors of safety and permanent deformations obtained during the design review phase are critical for future phases of the project, since research data shows that soil liner and textured geomembrane liner lack the proper shear strength for static and long-term seismic stability. One proposed solution is to raise the static factor of safety and reduce permanent deformations for the leach pad, as shown in Figure 9, by lifting a buttress at the leach pad toe. This buttress can be constructed with spent ore and can be built in two phases, by first building a relatively small one to assure stability during operation, and later increasing the buttress size to ensure long-term stability for the closure stage. This solution will involve a large earthworks activity, since the buttress is as large as 200 m long and 16 m high; this activity does not consider any cost previously accounted during construction or operation.

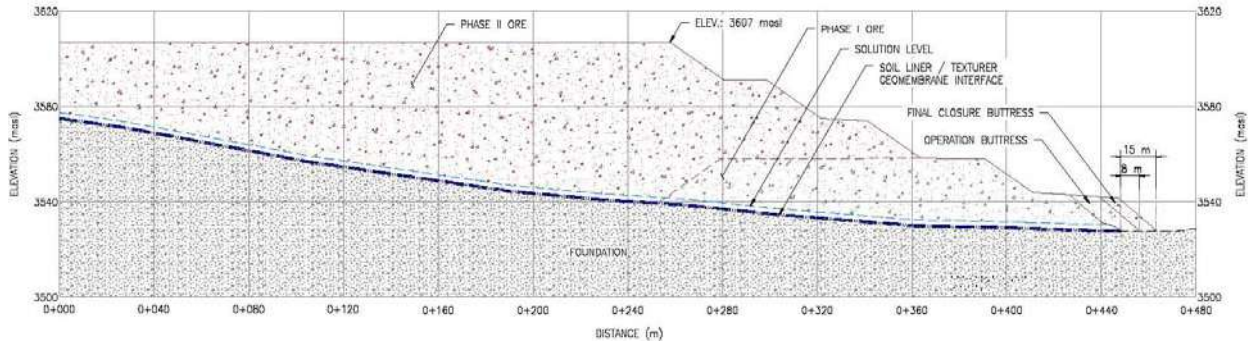


Figure 9: Leach pad cross section showing design configuration and the buttress proposed at toe

Other issues

The following issues have also been observed during heap leach pad construction and operation:

- Geomembrane quality should be verified before the product is shipped to the construction site. Once the geomembrane arrives at the site, problems detected before installation are very hard to resolve, and usually lead to construction schedule delays. Manufacturing quality assurance (MQA) is recommended for verifying the use of proper resin, measuring the minimum thickness based on project technical specification requirements, verifying quality control conformance testing and testing frequency, and so on.
- As part of the MQA, proper geomembrane texture needs to be verified; this should be similar to that used for interface shear strength testing during the design phase. If the texture is different or not as aggressive as expected, then LSDS must be performed and stability verified, if needed.
- Ore variability is very common in heap leach pads during operation, and ore properties are often not the same as assumed in the design phase, which is based on testing performed on a limited amount of samples; therefore, these properties should be verified frequently, depending on production rate and ore variability. The testing program should include global grain sieve analysis, plastic index, triaxial shear testing, staged hydraulic conductivity, point load tests, and geomembrane puncture tests.
- As engineering design is performed based on a limited field and lab testing program, an aggressive geotechnical monitoring instrumentation should be developed and installed in the leach pad and ponds. Vibrating wire piezometers, stand-pipe piezometers, inclinometers, vibrating wire settlement sensors, load sensors and strong motion accelerographs should be installed, depending on leach pad construction and operating conditions.
- Anomalous conditions of heap leach pad and related facilities have to be detected as part of daily, weekly, or monthly routine inspections and reported to the engineer of record. Annual

safety inspections by a senior geotechnical engineer, including geotechnical instrumentation data review and analysis, should be part of the common operating practice.

Conclusions and recommendations

- A new frequency of soil liner testing must be established in order to identify material variability detected during construction.
- CQC and CQA crews must be able to identify potential problems in materials in general, and in soil liners in particular, in order to prevent potential leach pad stability problems.
- The CQA engineer should be aware of any changes in borrow area material, in order to prevent high variability of soil properties and strength differences during construction compared with those used for design.
- QC and QA in the toe area of the leach pad must be much stricter than in the rest of the facility, as the stability condition of the entire facility is mainly controlled by the shear strength of the soil/geomembrane interface in this area.
- Any high variability of material properties in borrow areas, especially where these are used for the soil liner, must be communicated as soon as possible to the designer, in order to ensure that this issue will not compromise leach pad stability.
- In general, the strength properties of the soil liner and the geomembrane interface must be tested periodically during construction by performing LSDS, with a higher testing frequency for the material placed in the leach pad toe, in order to verify leach pad stability. The soil liner should also be tested for hydraulic conductivity. This is a very small investment that may prevent further problems requiring costly remediation after construction is completed.
- Bray and Travasarou (2007) present the most up-to-date method for calculating simplified seismic permanent deformations on earth structures; this is highly applicable to leach pad analysis and the failure mode it represents.

References

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