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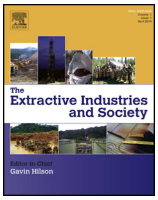

Original Article

Assessing the risk of leakage from heap leach pads used in mining operations

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ABSTRACT

Risk assessment is increasingly used in the context of mining activities, at various stages of mining projects. This applies also to mineral heap leach pads that are used for the recovery of gold, copper, silver and several other metals and non-metals. A heap leach pad consists of a lined facility (typically a composite liner) onto which ore is placed and then leached using, for example a strong acid or alkaline solution. This paper proposes an assessment of the risk of leakage through the composite liner of a heap leach pad, with the objective of illustrating how different types of uncertainty can be jointly propagated through the risk model. The proposed approach aims at avoiding the biases introduced by the common confusion between aleatory uncertainties (reflecting random variability) and epistemic uncertainties (reflecting the incomplete nature of available information). The joint propagation method provides estimates of the (imprecise) probability that leakage through the base of a heap leach pad should be lower than a certain value. It is shown how the proposed method aims to promote a more consistent approach to uncertainty representation and propagation in risk assessment, in order to contribute to the decision-making process in a more robust and transparent fashion.

1. Introduction

Recognizing the importance of mineral raw materials for Europe's economy, the European Commission issued the "Raw Materials Initiative" (COM, 2008), which provides guidelines for securing European access to mineral raw materials. Recommended measures include raw materials diplomacy for better access to raw materials on world markets, increasing resource efficiency via recycling and substitution, as well as extracting mineral raw materials from European sources. Consistent with the latter recommendation and also in response to the current economic crisis, many member states are reconsidering their mineral resource supply policies and contemplating the possibility of extracting, inter alia, base and precious metals from national sources. In France, for instance, several mineral exploration permits for base and/or precious metals were granted during 2013, an event which had not occurred for over a decade.

The successful development of mining projects depends on many factors and in particular social acceptance. A prerequisite for social acceptance is responsible mining (e.g., Goodland, 2012). The extractive industry has long recognized that it was in its best interest to promote responsible mining, hence the emergence of various initiatives such as the Extractive Industry Transparency Initiative (EITI) which aims at implementing high standards of investment transparency and accountability, and the promotion of best environmental practices. A useful tool for promoting transparency and increased social acceptance in the extractive industry is environmental risk assessment. Risk assessment is increasingly used in the context of mining activities, either at the mining project feasibility stage, for predicting potential environmental impacts, at the mining operation stage, for assessing for example stability during open pit (Chiwaye and Stacey, 2010) or underground mining activities (Cauvin et al., 2009), or at the post-mining stage, to assess health (Dinis and Fiuza, 2011; Glorennec, 2006) or erosion risks (Evans et al., 2004).

An important risk-relevant aspect of mining activity is the extraction of metal from mined ore by heap leaching. Heap leach pads are part of the mining process in the recovery of gold, copper, silver, uranium, nickel and several other metals and non-metals (Lupo, 2010; Thiel and Smith, 2004; Kappes, 2002; Hoye, 1987). A heap leach pad consists schematically (Fig. 1) of a lined facility (typically a composite liner) onto which ore is placed and then leached using a strong acid solution (e.g., sulphuric acid as in the case of copper or nickel ores), or a dilute alkaline cyanide solution (for gold and silver leaching; Kappes, 2002). As shown by several authors (Lupo, 2010; Breitenbach and Smith, 2006; Thiel and

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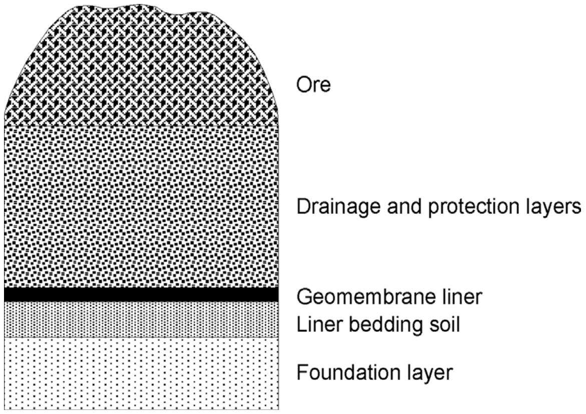

Fig. 1. Schematic of heap leach pad single-composite liner system (after Lupo, 2010).

Smith, 2004), the magnitude of recent heap leach pad operations are putting geosynthetic materials to the test, as leached ore heights may reach values of a few hundreds of meters resulting in loads exceeding 2000 kPa.

The most commonly used geosynthetics in heap leach pads are HDPE (high density polyethylene) geomembranes. This is because HDPE geomembranes have the best performance history in terms of durability and resistance to chemically aggressive solutions (see e.g., Hornsey et al., 2010). The resistance of HDPE geomembranes to acid mine leachate (AMD) from waste rock dumps or tailings has been studied by Gulec et al. (2004), who observed little short term degradation compared to municipal solid waste (MSW) leachate. With respect to long term performance, Fourie et al. (2010) suggest that mines in North America, South America and Australia that have used HDPE geomembranes for nearly 20 years have not shown indications of geomembrane liner degradation. According to Fourie et al. (2010), in mining operations with basic process solutions, only PVC liners have been found to degrade, but the degradation was attributed to exposure to high ultraviolet radiation rather than to the process solutions. As shown by Rowe et al. (2013a), geomembrane performance in heap leach pad applications depends primarily on the quality of the underliner. The shape of the underliner grading curve has a direct influence on the risk of geomembrane puncture, especially considering the vertical pressures involved. Other types of geosynthetics (e.g., geosynthetic clay liners or GCLs) may also be used as secondary liners (Hornsey et al., 2010). However, according to several authors, the performance of the bentonite in GCLs may be severely altered by acidic, alkaline or high ionic strength solutions, as they inhibit the ability of the bentonite to form a low-permeability gel (Shackelford et al., 2010). Moreover, considering the elevated temperatures that may occur at the base of heap leach pads (exceeding 50 °C; Thiel and Smith, 2004), particular attention should be given to the issue of GCL shrinkage (Rowe et al., 2013b).

The application of risk assessment to geosynthetics has been addressed by several authors. Sia and Dixon (2012), Basha and Babu (2010), Haddad and Shafabakhsh (2006), Shinoda (2007), Chalermyanont and Benson (2004), performed Monte Carlo analyses to assess the stability of geosynthetic-reinforced soil walls and slopes. Menzies et al. (2011) performed Monte Carlo analyses to assess risk reduction when utilizing geosynthetic clay liners in addition to soil liners. Haddad and Shafabakhsh (2006) underline the absence of formal relationship between the traditional safety factors used to compensate for uncertainties in loads and resistances and the probability of stability failure. Sayed et al. (2008), in a reliability assessment of reinforced soil walls under static and seismic forces, underline that traditional safety factors do not account for the variability and uncertainty of different parameters that influence the risk.

A review of quantitative risk assessments presented in the literature on geosynthetics shows that these analyses are typically performed within a classical probabilistic framework. Uncertainty with respect to risk model parameters are represented by single probability distributions (PDFs) and uncertainty propagation through the model is generally performed using the Monte Carlo method of random PDF sampling. However, as shown by several authors (e.g., Ferson, 1996; Ferson and Ginzburg, 1996), when available information is scarce or imprecise, selecting single PDFs can be problematic. In practical situations, it is common that certain parameters are not known in a statistical sense, but are instead informed using expert judgment. In such situations, the arbitrary selection of single PDFs introduces confusion between true aleatory uncertainty, reflecting random variability, and epistemic uncertainty, reflecting the incomplete or imprecise nature of available information. According to Ferson (1996), this confusion is one of the most common shortcomings in risk analysis. Such confusion has been highlighted by the Fukushima accident, where the traditional probability-based risk analyses have proven tragically inadequate.

It should be noted that some authors refer to epistemic uncertainty as "uncertainty", while aleatory uncertainty is referred to as "variability" (Oberg and Bergback, 2005). In accordance with the "Bayesian" school of thought (e.g., Lindley, 1971), these authors suggest that both sources of uncertainty can be accommodated in risk assessments using single probability distributions. But as shown for example by Dubois and Guyonnet (2011) and Ferson and Ginzburg (1996), different modes of uncertainty representation are suited to different types of information regarding uncertainty, whether reflected by measurements in significant numbers, expert judgment, or data in the literature, etc. The Bayesian approach of prior subjective probabilities finds its justification in the application of Bayes' theorem of conditional probabilities: as new data are collected, prior probabilities are "updated". But in situations where no additional information is gathered, the prior probabilities become posterior probabilities, thus artificially representing incompleteness as variability.

Recognition of the distinct difference between aleatory and epistemic uncertainty has led to the development of new methodologies that aim to bring consistency between available information and the manner in which information and associated uncertainty are represented. In this paper such a methodology is used to perform a semi-generic risk assessment for the case of leakage from a heap leach pad. The study gathers information relative to parameters that influence such leakage, while results illustrate the non-conservative character of calculations based on the assumption of single probability distributions in the absence of supporting information.

2. Methodology

2.1. Model hypotheses

Leakage is calculated for a single-composite liner using the empirical equation defined for circular defects (2 mm < defect diameter < 20 mm) and for good conditions of contact between the geomembrane and the liner bedding soil (Giroud, 1997; Touze-Foltz et al., 2008):

$$Q = 0.21 h_{\mathrm{w}}^{0.9} a^{0.1} K_{\mathrm{s}}^{0.74} \left(1 + 0.1 \left(\frac{h_{\mathrm{w}}}{H_{\mathrm{s}}} \right)^{0.95} \right) \quad (1)$$