Liquefaction in Dump Leaching[i]

By Mark E. Smith[ii], PE

General

Frequently defined as heap leaching of run of mine ore and occasional expanded to include large valley fill facilities, dump leaching is not a new technology. But the modernization of this old technology, using advances developed principally in the heap leach sector, has allowed us to build larger and higher dumps, faster than ever. It is this rapid expansion in geometry, combined with the precise engineering required in the containment and drainage systems, that marks the point of departure between heap leaching and dump leaching.

Mining has a hit-and-miss history of applying new technologies. In the case of mill processes, the history is one of mostly successes. In terms of tailings, it's a bleaker story with major dam failures still occurring at the rate of one every few years. In terms of general waste containment, our industry is responsible for a killer event once every 5 years with an average of 100 peopled killed each event. Arguably this is improving, but it might be too early to say. A recent search on the internet for the key words "mine waste failure" reported 147,000 hits.

Flowslide Liquefaction Defined

> *"…characterized by the sudden collapse and extensive, very to extremely rapid run-out of a mass of granular material or debris, following some disturbance. An essential feature is that the material involved has a meta-stable, loose or high porosity structure….The consequent loss of strength gives the failing material, briefly a semi-fluid character and allows a flow slide to develop."* (Hutchinson[1])

Liquefaction Potential

Liquefaction is a phenomenon of collapse and large deformation that can be triggered by a number of events. Liquefaction is caused by a combination of a collapsible material such as loose rock, water, and a collapse 'trigger' event. Classical liquefaction has as its trigger an earthquake. Dynamic failures are generally limited to relatively shallow (i.e., less than 20 meter) depths, since higher confining stresses reduce the susceptibility to this failure mode. They therefore are relatively limited in their destructive potential. A later-day form of liquefaction called static or flowslide liquefaction is only just becoming

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[1] Hutchinson, J.N., 1988. General Report. Morphological and geotechnical parameters of landslides in relation to geology and hydrogeology. 5th International Symposium on Landslides, Switzerland, Vol. 3, pp. 3-35.

understood and predictive models are being developed and field proven, the leading model having been advanced as recently as 1998 by Dawson, Morgenstern and Stokes[2].

Static liquefaction events do not require an earthquake to trigger failure. The trigger event is the introduction of water by rain, snow melt or, potentially, irrigation. Originally thought to be a problem of fine-grained wastes, the Aberfan, Wales disaster of 1966[3] made it clear that course rock was also susceptible. Unfortunately, it took the loss of 144 lives for this geomechanical reality to be brought to light. A recent study of Canadian coal waste failures suggests that nearly one-third of active coalmine waste dumps in British Columbia are potential high run-out flowslide hazards[4]. Run-out distances of several kilometres are common and some of the larger failures have included debris masses on the order of several million tonnes.

Flowslides are of particular interest because of their terrible, destructive history. In the last 4 decades and including all types of mine wastes, our industry has averaged one killer flowslide each 5 years with an average of 50 deaths per event. Beyond the sheer human disaster are the raw economic impacts, which can devastate any company.

Flowslides with Lost Lives

Event	Lost Lives
1962: El Cobre, Chile: Tailings failure.	250
1967: Aberfan, Wales. Coal waste dump failure.	144
1970: Mufulira Mine, Zambia. Tailings failure into underground workings.	89
1972: Middle Fork Buffalo Creek, WV, USA. Two coal dump failures.	125
1974: Bafokeng Mine, South Africa. Tailings failure.	9
1994: Merriespruit, Harmony Mine,, South Africa. Tailings failure.	17

The good news is that, to the author’s knowledge, there as not been a single case of flowslide liquefaction in heap or dump leaching (though dynamic liquefaction is a known failure mechanism). In fact, the nature of heap leaching – stack the material in thin lifts and then irrigate – tends to pre-collapse the rock and make it less susceptible to liquefaction (of any kind) than a waste dump, all other things equal. So, why are we concerned about this hypothetical failure mode in dump leaching? The answer lies in the fact that, in some regards, leach dumps are more like waste dumps then they are like

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[2] Dawson, R.F., N.R. Morgenstern and A.W. Stokes 1998. Liquefaction flowslides in Rocky Mountain coal mine waste dumps. Canadian Geotechnical Journal 35:328-343.

[3] Bishop, A.W. 1973. the stability of tips and spoil heaps. Quaternary Journal of Engineering Geology, 6:335-376.

[4] Piteau Assoc. Engineering Ltd. 1991. Investigation and design of mine dumps: interim guidelines. Report to British Columbia Ministry of Energy, Mines and Petroleum Resources.

heaps. The total heights are rapidly approaching 200 m, while few heaps exceed the 100 m threshold commonly associated with flowslides. The lifts are not thin and are now approaching 50 meters – much like a waste dump. They are built on variable and sometimes steep terrain. And they have two seriously negative features that make them ore susceptible than a "typical" waste dump:

- Unlike waste dumps in, for example, the North of Chile, dump leaches have ample water and an automatic trigger mechanism, both essential ingredients; and,
- There is usually a low strength liner system at the base of the dump, rather than a firm foundation, exasperating potential run-out distance and velocity.

Economic Costs of Major Flowslide Failures

Direct Costs	Costs to Industry
• Clean up of failure mass. • Restoration of dump or dam. • Environmental liability. • Restitution to victims/Off site damage. • Lost production. • Legal fees for settlement of claims. • Continuing costs for government and community relations programs. • Loss of shareholder confidence. • Increased costs for future expansions as government demands more security.	• Market wide loss of capital valuation in stock market. • Increased cost of financing. • Increased cost of permitting projects. • Higher insurance premiums. • Loss of shareholder confidence industry wide (the Bre-X syndrome). • Delays in permitting & financing. • Loss of ore reserves that are pushed out of the limits of marginal economics by the cumulative effects.

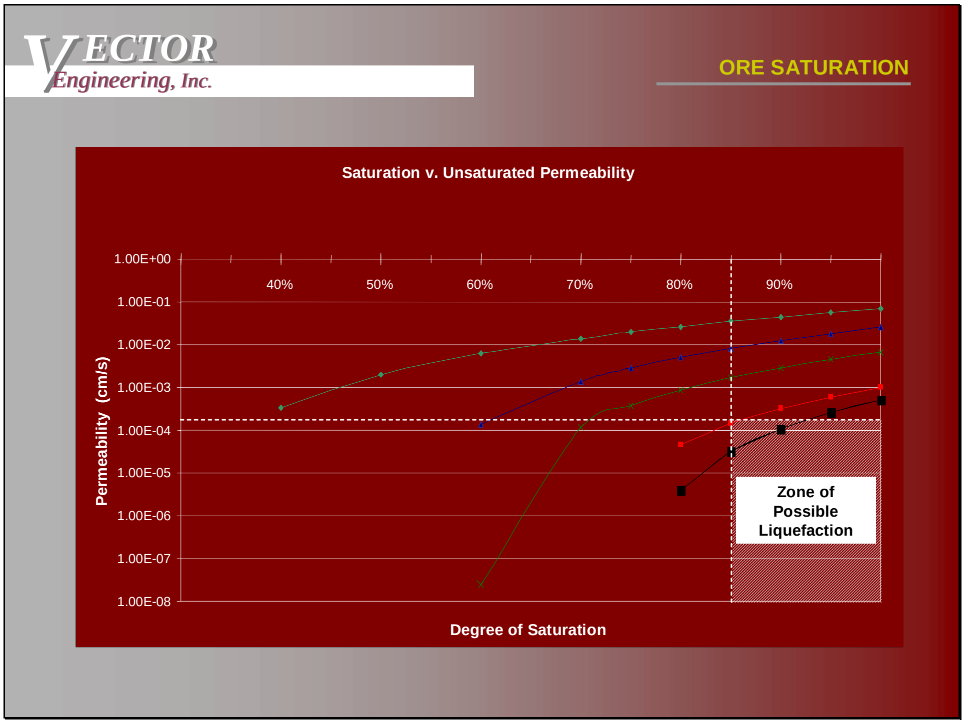
Using the Dawson-Morgenstern-Stokes model, the Piteau research and earlier contributory works, a working guideline for identifying leach dumps that might be susceptible to flowslide liquefaction might include some of the following.

Indicators of Flowslide Susceptibility

Parameter or Characteristic	Threshold (approximate)
Height	≥ 100 m
Foundation slope	≥15 degrees
Inter-bench slopes	Near angle of repose
Heaped moisture content of ore	≥ 5%
Saturated permeability of ore	$\leq 1 \times 10^{-2}$ cm/sec
Saturation (at any point in the dump)	≥ 85%
Other factors:	No toe support
	Finer material near the base

However, the models and applicable case histories are not sufficiently advanced to allow any such rules of thumb to govern the final analysis. Rather, these should be considered screening tools for preliminary design and the final analysis should include a specific consideration of this failure mode.

A very good first step in the analysis is to estimate the degree of saturation expected within the dump under leach. It has been estimated that liquefaction is unlikely if the degree of saturation is less than about 85%[5]. Solution application rates commonly quoted as flow rate per area (i.e., gpm/ft^2 or l/m^2/hr). Leach rates can also be expressed in the same units as permeability (cm/s). The typical application rate for leach solutions in both copper and gold leaching is between 1x10^{-4} and 5x10^{-4} cm/s. By comparing the application rate with the unsaturated permeability of the ore (which is a function, among other things, of the degree of saturation) the under-leach degree of saturation within the heap can be predicted. Typical values are shown in the graph. Based on these trends, if the saturated permeability of the ore is greater than about 5x10^{-3} cm/s one would not expect that the degree of saturation would exceed the threshold 85% and thus liquefaction would be unlikely. However, for lower saturated permeabilities, liquefaction may be possible and further analysis is recommended. It is also important to understand how the permeability will vary with depth and time.



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[5] Sassa, K. 1985. The mechanism of debris flows. Proc. of the 11th Int'l. Conf. on Soil Mech. and Foundation Engineering, San Francisco, V. 3, pp. 1173-1176.

Conclusions

For many projects the addition of a dump leach circuit, be it for ROM sub-grade ore or the re-leaching of spent ore (ripios) from a dynamic (on/off) pad, adds important profitability. Local communities gain from increased employment, tax revenues and, sometimes, an extended life of the mine. The industry experience with heap leach technology demonstrates that such technological adaptations as dump leaching can be accomplished without the problems we have seen in other areas. That is, assuming that the projects are properly planned and executed and this becomes more important as the facilities increase in size.

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