RISK BASED EVALUATION OF MINE WASTE DUMPS

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ABSTRACT

This paper reviews the nature of past waste dump failures, and examines their impacts. The geotechnical issues affecting hazard prediction are discussed from both design and operational perspectives. Methodology for evaluating the potential consequences of dump failures is presented and discussed. The methodology provides the basis for a risk-based approach which is explicit and defensible. Criteria for the acceptance of certain types and levels of risk are reviewed, and quantitative as well as qualitative approaches are described. The paper is intended to provide mine management with an effective tool for obtaining project approvals efficiently.
1.0 INTRODUCTION

The British Columbia Ministry of Energy Mines and Petroleum Resources (BCMEMPR) has initiated studies of the application of risk-based approaches to the design of mine waste dumps in the Province. The Phase I study, completed in 1992, developed a proposal for a Risk-based classification of Mine Waste Dumps (Reference 1). This proposal adapted accepted civil engineering risk assessment techniques to the large waste rock dumps commonly constructed at the coal mines of southeast and northeast British Columbia (Figure 1).

During the 1980's major expansion of the coal mining industry in British Columbia resulted in the construction of some of the largest and highest mine waste dumps in the world (Photo 1). In some cases, dumps over 400 m high have been advanced onto slopes steeper than 20 degrees to the horizontal. An increase in the frequency of major failures corresponded to the increasing rates of waste rock disposal and the increase in dump heights. This trend elevated concern among regulatory agencies and the public.

2.0 MINE DUMP PERFORMANCE AND DESIGN

A regional study of coal mine dumps (Reference 2) compiled and assessed data on dump performance and the factors affecting their stability. The study was carried out with the support and cooperation of each of the major coal mines in B.C. The eight mines involved in the study operated mine waste rock dumps under generally similar topography, climate, and foundation conditions. However, the rate of construction and the quality of the waste material consigned to the dumps varied considerably.

Many failures have resulted, in large part, from steep foundation slopes in excess of 25 degrees. Typically, coal mining in the mountains is economic only by open pit mining which commonly progresses from the highest elevation downward. It is necessary to dispose of mine waste rock by end-dumping from the upper slopes of the mountains. In these circumstances the mine operators have accepted certain levels of risk. In general, the likelihood of failure and the probable consequences of potential failures have been considered carefully by mine management (Photo 2).

Several technical issues regarding the stability of dumps remain unresolved, particularly where it is anticipated that one or more of the following adverse conditions may occur:

- pore water pressure may develop in lightly consolidated fine grained foundation materials, and/or,
- poor quality fine-grained mine waste may become saturated and,
- the above factors are exacerbated by high rates of disposal and the large dump face heights.

A number of research projects are being developed and executed to investigate some of these technical issues. The current state-of-the-art is a blend of analytical stability analyses coupled with discerning review of past experience. This experience has been documented in References 2 and 3. Designs for proposed new dumps should include detailed stability assessments for each stage of development, taking into account anticipated variations in the waste rock quality and the rate of dumping. Possible modes of failure should be evaluated, including:

- sliver failures of oversteepened dump faces due to fine-grained material and/or high rates of dumping,
- foundation failure due to excess pore water pressures which are unable to drain sufficiently quickly,
Figure 1: The locations of coal mines with waste dumps supported on steep mountainous terrain in British Columbia.
Photo 1: A 400 m high waste rock dump at Fording Coal Ltd.'s Fording River Operation in Southeastern British Columbia. This dump is one of the highest man-made structures in the world. The dump experienced failure in 1989, but has since been re-established and is currently performing satisfactorily.

Photo 2: The runout path of a highly mobile failure which probably involved some saturated fine-grained waste material. The debris travelled a distance of about 2.5 km, and skipped over a topographic spur 30m high as shown at the left side of the photograph.
• internal failure due to 'liquefaction' of saturated fine grained waste material.

Thus, experienced engineers can generally provide a reliable assessment of the hazard imposed by a particular dump development at any stage. It is worth noting that few abandoned or inactive mine dumps have experienced failures.

The consequences of past dump failures have been investigated and documented in References 4 and 5. Slide debris from some failures have run out distances of up to 2.5 km. Reference 4 documents the runouts for some 44 failures, and Reference 5 compiles and reviews available data on the environmental, economic/operational, and human health and safety consequences of the failures and their debris runouts.

With a few exceptions mine dumps have been operated safely, largely through the implementation of good monitoring practices at the dump crests. Impacts on human health and safety have been small. The few fatalities associated with the runout of failure debris have involved inactive dumps on steep foundation slopes. Monitoring of crest movements was not in progress at any of these dumps prior to failure.

Reference 5 is a study of the environmental and operational consequences of dump failures. This study is in progress at the time of preparing this paper. The approach and preliminary results of the study are described in Section 4 of this paper. A more detailed description and discussion of the results of this study will be provided at the presentation of this paper at the 1993 B.C. Mine Reclamation Symposium.

Table 1 shows an example of a dump stability assessment and a qualitative risk analysis. The information presented in Table 1 provides an explicit basis for subjectively or qualitatively evaluating risk. This approach, while not difficult, requires thorough and detailed analyses, and has been well received by both mine planners and regulators.

3.0 PROPOSED RISK-BASED CLASSIFICATION

A risk-based classification of mine dumps has been suggested by the B.C.M.E.M.P.R. as a tool that "will assist designers to determine the scope of design effort and to demonstrate the present and future security of the structure to the client, regulator and public."

Reference 1 describes a conceptually valid framework for a Risk Model. Ideally, the approach should be an integral part of good mine waste management. The explicit and defensible evaluation of hazards and consequences is important. Table 2 shows an example of rating potential consequences of dump failures. The proposed methodology would establish requirements for the scope of investigation and design, allowable site conditions, design criteria, monitoring requirements, and construction restrictions on the basis of a proposed dumping scheme.

Specific criteria cannot be established equitably until generic sensitivity analyses are performed to link the consequence of failure to the potential mode of failure and its predicted extent. These analyses span the disciplines of geotechnical, hydrological, and environmental sciences. Mine planning and economic aspects also need to be included in the risk analyses, if one accepts that trade-offs or compromises are inevitable for both economic and environmental criteria. Clearly both will have certain minimum acceptable standards.

The broad concept of risk-based management of mine waste is fundamentally important to achieving:

• a fair hearing from regulatory authorities and the public,
### Summary of Stability Assessment and Risk Analysis

#### Table 1: Example

<table>
<thead>
<tr>
<th>Dump Stage</th>
<th>CREST LENGTH (ft)</th>
<th>LOADING (BCY)</th>
<th>LOAD RATE (BCM/MI DAY)</th>
<th>CREST ADVANCE RATE (M/DAY)</th>
<th>ANALYSIS CROSS-SECT.</th>
<th>TOE SLOPE (deg)</th>
<th>FACE HT (ft)</th>
<th>FACE ANGLE (deg)</th>
<th>INDUCTED SAFETY FACTOR</th>
<th>Possible Event Type</th>
<th>Potential Event Cause</th>
<th>Event Risk Rating</th>
<th>Risk Duration</th>
<th>Possible Failure Vol (MPF 1005)</th>
<th>Probable Failure Rate</th>
<th>Possible Failure Run Out (ft)</th>
<th>Risk Assessment</th>
<th>Outcome Probability Rating</th>
<th>Outcome Relative Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>800</td>
<td>50</td>
<td>157</td>
<td>1,1</td>
<td>A</td>
<td>11</td>
<td>60</td>
<td>37</td>
<td>1.5</td>
<td>FINE/HOVERM</td>
<td>LOCAL SATUR/ORGAN/INDN</td>
<td>SHORT</td>
<td>1</td>
<td>RG</td>
<td>&lt;500</td>
<td>INCREASED SEDIMENT</td>
<td>M</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>800</td>
<td>120</td>
<td>376</td>
<td>5.0</td>
<td>B</td>
<td>14</td>
<td>320</td>
<td>37</td>
<td>1.4</td>
<td>FINE/HOVERM</td>
<td>LOCAL SATUR/ORGAN/INDN</td>
<td>SHORT</td>
<td>10</td>
<td>RG</td>
<td>&lt;1000</td>
<td>INCREASED SEDIMENT</td>
<td>M</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>1200</td>
<td>120</td>
<td>251</td>
<td>2.5</td>
<td>C</td>
<td>14</td>
<td>420</td>
<td>37</td>
<td>1.5</td>
<td>FINE/HOVERM</td>
<td>LOCAL SATUR/ORGAN/INDN</td>
<td>SHORT</td>
<td>10</td>
<td>RG</td>
<td>&lt;1000</td>
<td>INCREASED SEDIMENT</td>
<td>M</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>III-RECLAM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>D</td>
<td>0</td>
<td>300</td>
<td>37</td>
<td>2.4</td>
<td>FINE/HOVERM</td>
<td>LOCAL SATUR/ORGAN/INDN</td>
<td>SHORT</td>
<td>15</td>
<td>G/R</td>
<td>&lt;1000</td>
<td>INCREASED SEDIMENT</td>
<td>M</td>
<td>L</td>
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<td>FINE/HOVERM</td>
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<td>1000</td>
<td>R</td>
<td>&lt;5000</td>
<td>INCREASED SEDIMENT</td>
<td>M</td>
<td>L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**

- [1] Risk of outcome occurring as a result of event

**Legend:**

- **Failure Type**
  - I: Silting failure in upper part of face
  - II: Shallow slump parallel to dump face
  - III: Arches/palace wedge failure mechanism
  - IV: Mass failure extending well behind dump crest involving surface soil or dump fines
  - V: Mass failure involving sheet along slip surface parallel to end sear

- **Risk Assessment:**
  - EL: Extremely low probability of occurring (possible but extremely unlikely)
  - VL: Very low probability (could occur during dump lifetime but unlikely)
  - L: Low probability (unusual but likely to occur during dump life time)
  - M: Moderate probability: expected to occur occasionally
  - H: High probability: likely to occur frequently
  - REG: Regular occurrence, i.e. certain

Arbitrary assessment of relative probability of event cause occurring.

Arbitrary assessment of relative probability of outcome occurring as a result of failure.
<table>
<thead>
<tr>
<th>RATING</th>
<th>LOSS OF LIFE</th>
<th>ECONOMIC LOSS</th>
<th>ENVIRONMENTAL AND CULTURAL LOSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIGH</td>
<td>Potential for multiple loss of line affecting travelling and/or recreating</td>
<td>High economic losses affecting public, commercial, and mine facilities in</td>
<td>Loss or significant deterioration of nationally or provincially important fisheries habitat (including water quality), wildlife habitat, rare and/or endangered species, unique landscapes or sites of cultural significance. Feasibility and/or practicality of restoration and/or compensation is low.</td>
</tr>
<tr>
<td></td>
<td>public, and/or work force. Development within runout area typically includes</td>
<td>runout area. Typically includes direct damage to highways, railways, power</td>
<td></td>
</tr>
<tr>
<td></td>
<td>main highways and railways, service roads, haul roads and mine facilities.</td>
<td>lines, pipelines, buried telephone cables etc. Direct and indirect (interruption of service) costs could exceed $5 million.</td>
<td></td>
</tr>
<tr>
<td>MODERATE</td>
<td>Potential for loss of life affecting work force only. Development within runout</td>
<td>Appreciable economic losses affecting commercial and/or mine facilities.</td>
<td>Loss or significant deterioration of nationally or provincially important</td>
</tr>
<tr>
<td></td>
<td>area includes service roads, haul roads and/or mine facilities but no public</td>
<td>Direct and indirect (interruption of service) costs could exceed $500,000.</td>
<td>fisheries habitat (including water quality), wildlife habitat, rare and/or</td>
</tr>
<tr>
<td></td>
<td>facilities.</td>
<td></td>
<td>endangered species, unique landscapes or sites of cultural significance. Feasibility and practicality of restoration and/or compensation is high.</td>
</tr>
<tr>
<td>LOW</td>
<td>Limited potential for loss of life affecting work force only. No facilities</td>
<td>Economic losses do not exceed $500,000 and impact affects mine facilities only. However, there is reasonable potential for future development of other land uses within the runout area.</td>
<td>Loss or significant deterioration of regionally important fisheries habitat (including water quality), wildlife habitat, rare and endangered species, unique landscapes or sites of cultural significance. Feasibility and practicality of restoration and/or compensation is high.</td>
</tr>
<tr>
<td></td>
<td>within runout area other than service and/or haul roads.</td>
<td></td>
<td>Includes situations where the potential for impact is seasonally specific, but where such seasonal fish or wildlife use has a high probability of being avoided by adopting more conservative construction practices or cessation of dump construction during the period of hazard exposure.</td>
</tr>
<tr>
<td>VERY LOW</td>
<td>Minimal potential for loss of life. No facilities within runout area.</td>
<td>Economic losses do not exceed $500,000 and impact if any affects mine facilities only. Virtually no potential for future development of other land uses within the foreseeable future.</td>
<td>No significant loss or deterioration of fisheries habitat, wildlife habitat, rare or endangered species, unique landscapes or sites of cultural significance.</td>
</tr>
</tbody>
</table>
• cost effective design,
• restoration of lost trust in the design and execution of mine waste disposal,
• protection of human health and the environment

Classification

Risk-based classification should be developed on the basis of intimate understanding of the technical processes which link causes to their effects, i.e. failure modes to the impacts they cause. A section on risk based methodology and its application is included in the proposed British Columbia Mine Dump Handbook. The section on Risk Analysis will follow sections on modes of failure, methods of their analysis, and prediction of failure runout distance. The previously proposed Dump Stability Rating system was not adequate, and thus was not generally accepted, because:

• it failed to recognise inter-relationships between each category rated, and
• no account of consequence of failure was included.

The proposed Risk Based Classification system depends on the resolution of the fundamental issue of characterising the consequences of failures.

The reliability of the proposed methods of analysis of hazard and consequence must be established before acceptance criteria are established for the risk based classification system. The mining industry is unlikely to accept the proposed risk classification system unless the building blocks of hazard and consequence analyses are seen to be satisfactory. Thus, the proposed CLASSIFICATION is premature but the overall RISK BASED approach of explicitly describing the hazards and consequences is fundamentally desirable. We should not try to classify nor to define acceptance criteria for the consequences of failures until these criteria have been defined explicitly.

Need for a Classification

The need for a classification deserves some discussion. We perceive that the incidence of failures peaked before 1989, and may have decreased since. The failures have not occurred without warning provided operational procedures have been in place to detect and to react to the signs of accelerating movement. However, the perception of a loss of control stems from the difference between predictions of performance, prepared for the Permitting process, and the actual performance during operations. It should be noted that a number of dumps have received Regulatory approval where some risk of failure has been clearly stated. In other cases failures have developed as a result of technical issues that are not completely understood or which are very difficult to model reliably. In other cases, major design assumptions have been violated due to operational factors outside the control of the designer.

4.0 CONSEQUENCE PREDICTION

There is a need to refine the prediction of failure consequences, in addition to the task of resolving methods of hazard analysis (which should be achieved by the Mine Dump Handbook). The need to refine prediction of consequence can be sub-divided as follows:

• Runout prediction in terms of expected distance, ideally a probability density function, but in the short-term characterised as upper and lower bounds, and expected values.
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- Prediction of impacts of the runout in terms of water quality, habitat quality or loss, nature and cost of reclamation and clean up, and nature and cost of mitigation measures such as barriers or deflection berms. Ideally, the ranges of these impacts should be expressed as probability density functions, but only qualitative assessments may be practical.

The current study focuses on the prediction of consequences of failure. The first step is an objective review of case histories in terms of documented consequences and costs. The following information is being sought for specific failure events:

- changes in water quality with time following failure events,
- effectiveness of sediment control facilities in place at the time,
- did runout exit property?
- did runout exit the proposed ultimate dump limits?
- did runout debris adversely affect ultimate dump stability and/or capacity?
- what changes in the failure debris have occurred with time?
- what are the effects of major storms?
- is reclamation of slide debris planned and at what cost?
- what was public reaction to failure, both immediately following and over long-term?
- what loss of life (whatever form), or degradation of habitat has been estimated or measured?
- have any events been major disasters by virtue of clean-up being impracticable or prohibitively expensive?
- did some of the events have the potential to have been far worse?
- how does environmental contamination and loss compare with other industries such as metal mining, pulp processing, forestry, and heavy industry? This information should be expressed in terms of measurable parameters such as area and duration of impact.

Wherever possible, subjective opinion is being excluded. Collection and compilation of this information is relatively straightforward given the current atmosphere of cooperation between the major mining companies, most of which run substantial environmental groups, and government ministries. These groups are providing much of this data with modest effort. The motivation for this effort is to improve confidence in risk prediction, avoid imposition of blanket classification systems, and to facilitate project assessment and acceptance. Risk acceptance criteria may evolve subsequently if common trends are identified.

The Phase II study was commissioned by the BCMEMPR in February 1993 for purposes of assessing the consequences of mine waste dump failures (Reference 5). The objectives of the study were to characterise mine
dump failure consequences for purposes of developing a defensible risk assessment model for use in selecting waste
dump sites, dump design and mine permit evaluation.

Representatives of the B.C. Ministry of Environment, Lands and Parks (MELP), the B.C. Ministry of
Energy, Mines and Petroleum Resources (MEMPR) and the operating mines at which failure events, selected for
consequence assessment, have occurred were contacted in early February, 1993. Field reconnaissance of the sites
located in the Sparwood/Elkwood and Tumbler Ridge areas were conducted during the week of February 22 to 26
and March 10 to 12, 1993, respectively. Discussions with these representatives were held, failure event site visits
were conducted where access could be gained and documentation related to each of the events was obtained. The
results of the data collection and discussions were synthesized into a data base for purposes of constructing a
consequence rating method such as that presented in Table 2. The results of this study, which was nearing
completion as this paper was submitted, will be presented at the Mine Reclamation Symposium to be held in May,
1993.

Generally, the consequences related to the failure events examined to date varied depending upon the time
of year, the facilities in place and the remedial action taken immediately following the event. In the majority of
cases, the slide runouts remained within the approved ultimate dump limits and have since been covered by waste
material. Several other events extended beyond the final dump limits. The mine operators were diligent in all cases
in implementing remedial action and contacting the regulatory authorities immediately following all slide events.

Settling ponds and drainage control structures, designed to handle sediment loads generated by spring
runoff, 24 hour precipitation events and Q-10 flows generally were efficient in mitigating runoff generated from
waste dump failure events in the short and long term. With the exception of one event, these facilities were in place
at nearly all mines prior to the failures. The remedial action taken in this case included an emergency sediment
pond which completely mitigated any water quality impacts in the receiving waters. However, fisheries resources
were impacted by the slide because it occurred when the creek was populated with overwintering fish. In this case,
consequences of the failure would have been worse in terms of water quality, but less in terms of fisheries resources
had the event occurred during spring runoff.

Mine operations were inevitably affected by failure events because of the need to find alternate dumping
locations while the waste dump stability was confirmed and the failure crest rehabilitated. In only one case was the
dump completely abandoned for an alternate location but with no loss of production.

Consequences to the public included the loss of life on two separate waste dump failure events. One event
buried a vehicle when the slide debris crossed Highway No. 3 near Sparwood, B.C. The incident would not have
occurred today given the present knowledge of mine waste dump design and management. A second event in 1992
claimed the life of a mine worker. The incident was not anticipated as the waste dump had not been active for over
a year prior to the slide event and monitoring of displacements in the region of the dump crest had been
discontinued. It was this incident that lead to the mine waste dump audit in the Province in 1992 and increased
awareness of the requirement for continuous monitoring of waste dumps and miscellaneous fills.

Overall, the explicit description of hazards and consequences, even if qualitative as in the example in
Table 2, will go a long way towards allaying regulatory concerns. A common-sense approach to evaluating this
type of information should be a defensible basis for approval and should not penalise industry.
REFERENCES


