RECENT PROBLEMS WITH WASTE ROCK SPOIL DUMPS

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ABSTRACT

Several failures of rock waste spoil dumps have occurred in the past few years in British Columbia. A review of three dump failures is provided. General details are described including the mechanics of the failure.

Recommendations are presented to develop procedures to reduce failures of these types in the future.

Problèmes récents avec les sites de dépôt pour déchets rocheux

par

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Plusieurs ruptures de sites de dépôt à déchets rocheux se sont produites au cours des dernières années. Cette communication décrit les détails généraux ainsi que la mécanique de rupture. Des recommandations sont présentées pour développer des procédures visant à réduire les ruptures de ce type dans le futur.
INTRODUCTION

Spoil dumps at many locations in British Columbia have failed commencing in the late 1960's. The majority of these have occurred at coal mines. In one instance two lives were lost, in another a sedimentation pond was partially destroyed and in a third, a large river was dammed for about 24 hours.

In steep mountain areas some of these dumps are over 350 metres in height, which classes them as the highest man-made geotechnical structures in the world.

Moving waste rock to dumps is a mining cost which generates no income. As a result there is a tendency to limit geotechnical stability investigation and analyses to a minimum with limited attention paid to foundation evaluation prior to dumping. In addition, construction related expenses are minimized.

As a result of recent failures, the Department of Energy, Mines and Petroleum Resources of B.C. and CANMET in Ottawa have initiated 5 separate studies with a view to developing Guidelines for Spoil Pile Investigation, Analysis, Design, Construction and Monitoring. This initiative is commended.

CASE EXAMPLES

A review of three dump failures having different mechanisms is presented. The different mechanisms illustrate the difference that site conditions can play.

Typical site investigation procedures to reduce the risk of failure are outlined.

Site 1 - Figure 1 and 2 show a steep mountain slope where an over-steepened spoil dump moved several hundred meters. The slope below the movement gradually flattens. However, if the material in the dump were to become near saturated and gain momentum, an adjacent small creek could be dammed and the mill site below become subject to some risk.

The spoil dump site is located in the area of a major ancient rock slide that created a lake. To minimize heavy concentrated loading the dump was to be spread over a moderate surface area.

During the early months of dumping, weathered rock was encountered which deteriorated and excess fines, up to about 26 per cent by weight, developed. In addition, remnant ice lenses were encountered which added moisture. The upper slopes were covered with shrubs and minor organic cover. The dumping was performed by pushing with a caterpillar tractor.

The upper slope became oversteepened with slopes ranging up to 42°. The presence of fines and nominal moisture imparted some temporary cohesive strength in the waste material. As dumping continued the slope commenced to bulge and subsequently to fail.

After the overall movement, two seepage zones were observed near the original toe of the dump. Dump movement over the seeps likely created some pore pressure adding to the mobility of the dump mass. The movement developed flow characteristics and moved several hundred metres until stopping where the slope gradient flattened.
Figure 1 - Aerial view of the spoil dump site. Note the potential runout area if the dump failed as a flow failure. A diversion berm is recommended lower on the slope.

Figure 2 - Close-up of the flow slide area (c). The portion at the left (a) has behaved normally. The central portion (b) has cracked. Note the old slide area (d) on which the dump encroaches.
Had the volume been much greater, the mass would likely have gone much farther.

The failure was due to an excessively steep dump face developing, the presence of weak plastic material high moisture content in the spoil, and an excessive volume dumped over a short length of dump.

Recommendations included the following:

- Employ a much longer dump crest length to reduce the loading rate.
- Spread cohesive or wet material uniformly on the top of the dump rather than push over the face.
- Monitor the face angle and crest movement at least daily.
- Delay production holes in the nearby pit to reduce seismic forces.
- Divert surface water away from the face.
- Construct a 10 metre high diversion dyke above the plant site.

Site 2 - Figure 3 shows a major spoil pile failure at a coal project. Several million cubic metres were involved. The creek in the valley was dammed and considerable spoil flowed several hundred metres up the opposite valley slope. The movement obviously developed a high speed.

Figure 4 shows the material shape and gradation in the valley after the movement.

The dump was being developed in a gully. Based on experience with other dumps at the mine a stability analysis using a multiple wedge type geometry was performed. This analysis assumed the dump would be continued until it filled the gully.

Dumping continued by extending the dump face outward beyond a straight line between the gully flanks. As dumping continued the outer slope developed active movement comprising slumping and consolidation. The rate of movement was being monitored with tripod wire extensometer monitors. Movements began to accelerate and dumping was halted. Five hours before failure the movements had reached 1000 cm per hour. Once in motion the movement accelerated rapidly to high speed. On reaching the valley floor the thicker organic overburden and creek water added mobility to the movement.

The failure dammed the creek and created a pond. After several days the pond water started to permeate through the spoil. Initially the water was dirty but later flowed clean.

Observation of the spoil gradation after failure revealed most of the material had become significantly rounded. This resulted from the large movement within the dump. Considering strength of the material, the angular angle of friction of about 37° likely reduced by 3 - 4 degrees. This resulted in a reduced safety factor and contributed to the failure.

Extending the dump face out beyond the gully flanks created a load increase at a greater rate than the surface contact area increase. This resulted in excess stress and also contributed to the failure. The mobility of the slide was aggravated by the steep slope, weak surficial valley floor material and water in the creek.
Figure 3 - Major dump failure constructed in a gully. Dumping extended out beyond a line between the gully flanks. This overstressed the foundation materials.

Figure 4 - Rounded rock in the slide area. These materials have degraded due to excessive movement. The friction angle is reduced at least 3 - 4 degrees from their original angular shape. This contributed to failure.
Recommendations included the following:

- Develop an analysis model for a dump geometry that extends beyond a line joining the gully flanks.
- Reduce the allowable movement rate.
- Allow for material degradation and strength loss in the stability assessment.

Site 3 - A spoil dump was being developed on a river floodplain. A geotechnical investigation was performed in the proposed area of the dump. This revealed loose fine grained silt and clay silt lacustrine soils with sand layers and a high water table. The design for the dump allowed up to a 15 metre high lift provided pore water pressure dissipation occurred moderately rapidly. Piezometers were installed to evaluate pore pressure.

Dumping was commenced on the flood plain and some months later a foundation type failure developed. The flood plain at the toe of the dump and multiple displacement with multiple scarps developed on the top of the dump (Figure 5). Unfortunately this failure was not back analyzed and a new dump design criteria was not developed. No change in dump height was made.

About two months later the dump area south of the first slide failed rapidly with material moving up to 550 metres toward the river and disrupting the river (Figure 6 and 7). The foundation lacustrine soils had obviously liquified due to an excessive build-up in pore water pressure under the load of additional spoil materials. An estimated 1.5 million cu. metres of material moved.

No one was in the slide area at the time. However, 6 survey and drill crew members had been working in the area up until about 7 hours previously. Considerable construction equipment and 1 drill was caught in the slide. All trees on the floodplain below the dump were destroyed.

Since the major movement occurred the area has been stable. This is to be expected since the material would have reached residual strength (the lowest possible strength).

After the surface dried out it was safe to gain access to the slide and remove the equipment.

The cause of the slide was a combination of excess dump load and the associated high build-up of pore water pressure which did not dissipate reasonably rapidly as had been expected.

Recommendations included the following:

- Perform back analysis of stability of both slides to more accurately determine soil strength and hydraulic conductivity parameters in the floodplain soils.
- Perform an evaluation of the effect of the slide on the river regime.
- Do not dump any further material on the floodplain until a comprehensive geotechnical and hydrogeologic investigation is performed.
- Control production in the nearby pit to reduce seismic impact.
Figure 5 - Slump failure in foundation lacustrine soils due to excessively high dump and slower pore pressure dissipation than expected. Note the top slump area (a) and the toe heave area (b).

Figure 6 - Overall dump failure which moved about 550 metres laterally and encroached on the river. The lacustrine soils liquified due to overloading Mn excessive failure; strain.
GENERAL RECOMMENDATIONS

The three case examples of spoil dump failure cited illustrate that a variation in site conditions can lead to dramatically different types of failure. As a result, geotechnical and hydrogeological investigations must be established to recognize and take into consideration those differences.

After the general location and potential range of volumes have been established the site investigation program should be formulated. It is obvious that more detail and care in the investigation is essential than had been used at many sites in the past.

The most important features of the investigation should include the following:

Site conditions - Topography, vegetation, surface hydrology, precipitation, temperature.

Foundation conditions - Organic soils, overburden soils and bedrock stratigraphy.
- Seepage and pore water pressure profiles.
- Depth of weathering.

Materials properties
- Shear strength, compressibility and hydraulic conductivity of all foundation and dump materials.
- Degradation of dump materials with time and movement.

Stability Analysis - Evaluate the most likely mode of failure(s) and perform stability analyses, preferably in the form a safety factor. Include seismic stresses where applicable.
Develop the dump design.

Dump Construction Procedures - Develop the dump in sequence and monitor the rate of dumping vs movement, influence of precipitation, etc. Select the location for weak materials, develop through, under or around dump drainage.

Monitor Movement - The measurement of surface movement - in the predominant direction of movement - will assist in the control of dump stability. Develop criteria for maximum rate of movement. Prepare daily, weekly and monthly dump reports. Back analyze any failure to use in urgent redesign.

CONCLUSIONS

Many spoil dumps in British Columbia are massive soil - rock structures. Experience to date with many failures indicates that a general deficiency exists in the geotechnical and hydrogeological investigations, material property, evaluation, stability analysis of the most likely failure mode, dump construction techniques and monitoring procedures.

This paper outlines some of the key areas of investigation and design and construction that should be improved.