Geotechnical stability considerations in the design and reclamation of tailings impoundments

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ABSTRACT: Mine tailings impoundments are primarily geotechnical structures. By description of three case histories, the effects of geotechnical factors on the stability of tailings impoundments are discussed. When designing a new impoundment it is possible to incorporate proper consideration of appropriate reclamation procedures. Examples are good sites, durable materials, embankment layouts that blend with surrounding topography, and provision for final reclamation surface shapes and, where appropriate, covers. With impoundments that were completed many years ago to what are now inappropriate standards, extensive remedial actions may be necessary to provide for long-term stability; work required may include relocating the pile, reshaping the pile, and providing expensive erosion control facilities.

1 INTRODUCTION

Tailings impoundments are usually the largest structures that result from a mining operation. They can and often do have a greater environmental impact than any other aspect of the mine, including, for example, the mine excavation.

In designing and constructing impoundments to be economic during disposal operations and to provide for cost-effective reclamation, it is necessary to consider many geotechnical factors that relate primarily to the long-term durability and integrity of the construction and disposal materials and hence the structure.

This paper explores these ideas by examining three case histories of the design and construction of tailings impoundments.

2 GENERAL CONSIDERATIONS

A tailings impoundment is a geotechnical structure in that it consists of ground-up soil and rock, placed on a soil or rock foundation, and retained by engineered soil and rock containment dikes or embankments. Drains may be placed in the impoundment to direct and control seepage. Moreover, the whole impoundment fits into the geomorphic terrain of the site and is subject to the same geomorphic forces that sculpt the landscape in both the short and long term.

Geotechnical factors that affect the stability of a tailings impoundment are: the site selected, topography at the chosen site, geomorphological agents, the layout of the impoundment including the design of the dikes and retaining embankments, and the properties of the materials of which and on which the impoundment is constructed.

Instability may be caused by short-term extreme events such as floods, fires, drought, earthquakes, and so on. Instability may also be caused by long-term factors such as erosion, sedimentation, biological penetration, weathering, and leaching. Methods to control the potential instability of impoundments vary with site conditions, design requirements, and standards. This is illustrated by the case histories.

3 CASE HISTORY #1, CANNON MINE

The design and construction of the Cannon Mine tailings impoundment are described by Caldwell et al. (1986).

The impoundment will contain three to four million metric tons of tailings from a gold mine on the outskirts of Wenatchee, Washington. The mine is at the foot of the Cascade Mountains which rise in a series of ridges and valleys from the alluvial terraces that border the Columbia River. The impoundment is in one of the valleys. The area is dry, the summers hot, and the winters cold. The bedrock is interbedded siltstones and sandstones; the tailings are derived from the crushed sandstones in which the gold is found.

Twelve alternative sites were examined. The advantages of the chosen site include its proximity to the mine, low visibility, existing impact from silica mining, suitable foundation soils and rocks, competent construction materials, and a topography into which the impoundment blends for long-term stability.

An engineered embankment of soil and rockfill was chosen in preference to construction of an outer dike with tailings. Because of the proximity of the impoundment to populated areas and because the reservoir could fill with water from the Probable Maximum Precipitation, the embankment was designed and constructed as a water retaining structure.

In order to provide for long-term stability of the embankment, the soils at the site were stripped to bedrock. To improve the economics of construction, some fill in the lower valley was left in place at the upper and lower end of the embankment. A grout curtain was installed beneath the core. The embankment was constructed of materials from a borrow close to the site. The core is low permeability compacted clayey silt that will significantly impede water flow from the reservoir. The shells are compacted decomposed basalt. The coarser fractions of this material were placed on the downstream face of the embankment which provides for long-term control of erosion down the face of the embankment.

Reclamation will be achieved by contouring the surface, creating a suitable surface cover and drainage channels, and establishing vegetation. The surface will be contoured during the final years of operation by managed discharge of the tailings to form contours that direct surface flow to a riprap-lined channel at the outer edge of the tailings surface and the south side of the valley. This channel will discharge into a spillway cut into the rock on the right (i.e. south) abutment of the embankment. This arrangement provides a topographic form that has a stability equivalent to that which existed in the area before construction of the impoundment.

4 CASE HISTORY #2, AMBROSIA LAKE

The Ambrosia Lake site is in northwest New Mexico. The pile is to be reclaimed under the terms of the Uranium Mill Tailings Remedial Action Project, which provides for stabilization of inactive uranium mill tailings piles for a design life of 1000 years, where reasonably achievable, and at any rate for 200 years.

The pile is almost square with sides about 1000 meters long. At the south end the pile is about 15 meters high, and, because of the sloping site, about 1.5 meters high at the north end. The tailings are saturated, soft, very fine-grained clayey silts. The tailings in the outer part of the pile are sandy because pile operation involved upstream construction by perimeter spigot discharge.

Details of the pile reclamation are given by DOE (1985). The pile will be reshaped by relocating the thinner northern part of the pile and placing this material to fill the existing bowl or depression in the center of the pile. Thus the top surface is shaped to drain all runoff from the pile. In order to reduce radon emanations to the EPA standard of less than 20 picocuries per square meter per second, a radon barrier of compacted weathered clay will be placed over the pile. The radon barrier will be covered with a filter and rock layer. The gradation of the rock is chosen so that it will remain in place even when runoff from the Probable Maximum Precipitation flows over and around the pile. The rock is a durable basalt that is not expected to weather significantly during the design life of the pile.

Large swales will be excavated around the pile both to provide the radon barrier material and to direct flow from the upstream catchment area around the pile. Ground-water protection is achieved by placing the low permeability radon barrier. This inhibits flow of water through the tailings and into the ground water.

By reshaping the pile, providing

perimeter drainage, and by covering the tailings with a clay and durable rock cover, the pile is reclaimed and will be stable for a long time in the future. The environment is protected from windblown tailings and the ground water from excessive seepage.

5 CASE HISTORY #3, CANADIAN SITE

In a report to the Canadian National Uranium Tailings Program, Robertson et al. (1986) examine the long-term stability of different generic decommissioned Canadian uranium mill tailings impoundments. A generic facility representative of those in Saskatchewan is:

- o Tailings deposited by wet mass discharge behind an embankment with two horizontal to one vertical sideslopes, a central core of glacial till, drains, an upstream shell of compacted tailings sands, and a downstream shell of sand and gravel.

Table 1 is an evaluation of the potential for instability of this and a similar impoundment.

The potential for instability in the long term is moderate. Because the sideslopes of the embankment are steep, there is a severe potential for deep gully erosion. The potential for drain plugging due to solifluction, root action, and frost is moderate. Instability of the diversion ditch is categorized as severe. Seepage water quality will be poor.

Robertson et al. (1986) assess possible ways to stabilize these facilities and conclude, inter alia:

- o Heavy rock riprap is required to control erosion.
- o Reduction of embankment catchment areas and flattening of slopes to provide sacrificial material may also be appropriate ways to deal with erosion.
- o Gravelly till, waste rock, and riprap will control wind erosion.
- o Filter layers may prevent drain plugging.
- o Chemical precipitation blocking of drains may be controlled by: keeping the drain flooded; providing surplus drain capacity; and constructing embankments of free-draining material which will allow passage of seepage water when the drains are blocked.

Table 1. Potential for impoundment instability.

Site:	A	B
Factor		
EMBANKMENTS		
o Sheet erosion	m	m
o Gully erosion	S	S
o Flood erosion	m	m
o Wind erosion	M	M
o Drain plugging	M	S
o Frost action	M	M
o Seepage erosion	m	S
o Physical instability	M	S
DIVERSION WORKS		
o Floods	S	S
o Gully erosion	S	S
o Ice & debris blockage	S	S
o Sediment blockage	S	S
SURFACE WATER QUALITY		
o Without treatment	M	S
o With treatment	m	m
o Seepage	M	S

Notes: n - none; m - minor; M - moderate; S - Severe

- o Surface-water contamination may be prevented by placing covers that preclude contact between surface water (precipitation runoff) and the tailings.
- o Discharge of contaminated seepage to the ground and surface water may be prevented by placing thin soil covers or installing an infiltration barrier with an overlying drainage layer.

The authors conclude that the details adopted in the U.S. for inactive uranium mill tailings impoundments, an example of which is the second case history in this paper, are probably also an appropriate approach to meet the defined requirements for Canadian tailings reclamation. The thickness of the different layers should vary according to local needs and conditions. Although details may vary according to local design methods and assessed needs, it is generally necessary to consolidate tailings, flatten slopes, and place low permeability covers, filters, and riprap to prevent erosion.

6 CONCLUSIONS

This paper discusses modes of geotechnical instability of tailings impoundments in a variety of climates and political jurisdictions. The paper shows by way of three case histories that similar approaches are applicable, regardless of the place and environment of the pile, if the objective is to preclude long-term instability.

Relocating tailings from poor sites, reshaping piles, flattening embankment and dike slopes, and covering piles with low permeability material and erosion resistant, durable rock, are appropriate methods to provide long-term geotechnical stability.

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