PROPERTIES OF TAILINGS DAMS

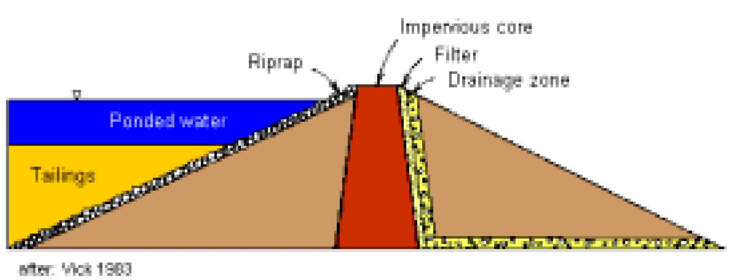
What are tailings?

Tailings are the residue of the milling process used to extract metals of interest from mined ores or to clean coal. During this process, ores are milled and finely ground, and then treated in a flotation and/or hydrometallurgical plant. The extracted metal represents a small percentage of the whole ore mass and so, the vast majority of the mined material ends up as a finely-ground slurry. Tailings contain all other constituents of the ore except for the majority of the extracted metal. These consist of heavy metals and other substances at concentration levels that can be toxic to biota in the environment. Moreover, tailings contain the chemicals added during the milling process, although these levels and types are generally not of major concern. After milling, these contaminants are better available for dispersion into the environment than in the original ore because of their finer particle size and higher surface area. Furthermore, the mechanical stability of the tailings mass is poor because its small grain size and high water content.

Tailings impoundments

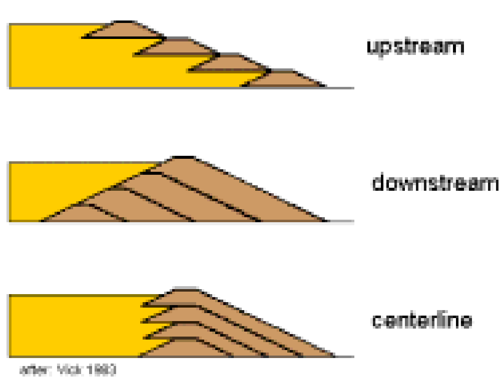
Most mill tailings produced worldwide are dumped in large surface impoundments ("tailings dams"). In other cases, tailings are processed for use as backfill in underground mine workings. The embankments of these large impoundments are typically constructed as earth-fill dams. Although water-retention dams are suitable for use, their cost is too high.

Water-retention type dam for tailings storage



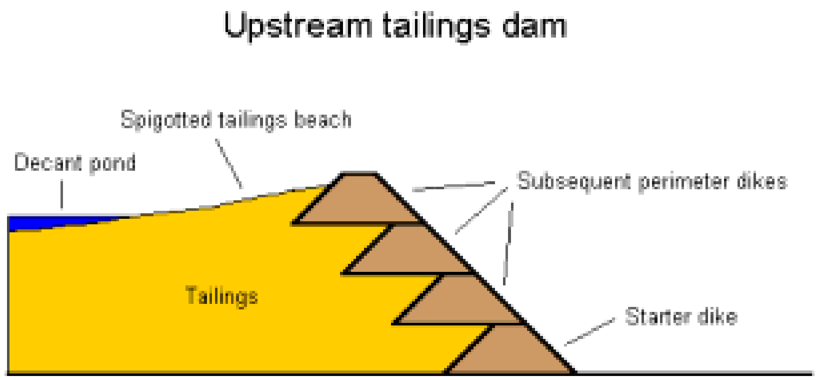
Unlike water-retention dams, tailings dams usually are not initially constructed to completion but rather, are raised sequentially as the impoundment fills.

Types of sequentially raised tailings dams



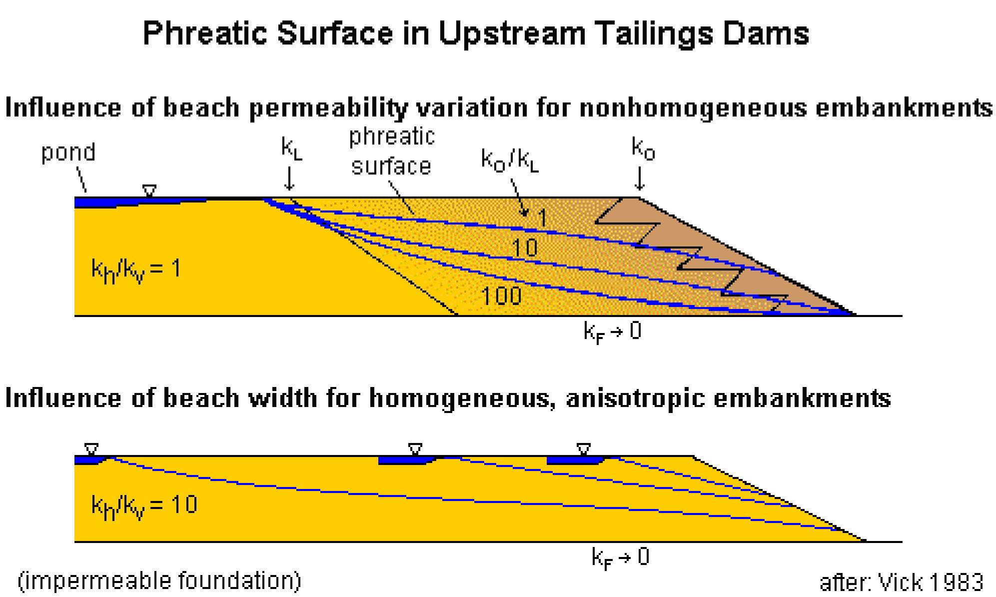
UPSTREAM TAILINGS DAMS

Upstream-type embankments are the most popular embankments for tailings dams; new parts of the embankment are built on top of the slurries impounded during the previous stage - the dam crest thus moving "upstream".



Because of its low cost, the upstream method is used with most tailings dams worldwide, but it must be built and operated with great care and attention as it has the highest risk of failure of all the methods. Dam stability is of great concern with this type of tailings embankments:

- The phreatic surface is critical for dam stability. Dam failure can occur, if the **beach width** between the decant pond and the dam crest becomes too small - from flood inflow, or from improper mill operation. While the determination of phreatic surface location is important for upstream-type embankments, it is more complex for this method than for any other type of tailings-retention structure.



k_L = permeability at the edge of the ponded water at the slimes zone
k_0 = permeability at the spigot point (dam crest)
k_F = permeability of foundation
k_h / k_v = anisotropy ratio (horizontal vs. vertical)

- Upstream dams are highly susceptible to **liquefaction** under severe seismic ground movement. This may result from earthquakes, from mine blasting, or even from the movement of heavy equipment.
- Upstream dam stability is endangered if the **rise-rate** of the dam is too high. Raising rates greater than 15 m/yr can be hazardous as the tailings particles need tome to consolidate to their highest permeability. If the particles do not settle sufficiently, this can produce excess pore pressure within the deposit, decreasing stability.

Comparison of Surface Impoundment Embankment Types

	Water Retention	**Upstream**	**Downstream**	**Centerline**
Mill Tailings Requirements	Suitable for any type of tailings	At least 40-60% sand in whole tailings. Low pulp density desirable to promote grain-size segregation	Suitable for any type of tailings	Sands or low-plasticity slimes
Discharge Requirements	Any discharge procedure suitable	Peripheral discharge and well-controlled beach necessary	Varies according to design details	Peripheral discharge of at least nominal beach necessary
Water Storage Suitability	Good	Not suitable for significant water storage	Good	Not recommended for permanent storage. Temporary flood storage acceptable with proper design
Seismic Resistance	Good	Poor in high seismic areas	Good	Acceptable
Raising Rate Restrictions	Entire embankment constructed initially	Less than 4.5 - 9 m/yr most desirable. Greater than 15 m/yr can be hazardous	None	Height restrictions for individual raises may apply
Embankment Fill Requirements	Natural soil borrow	Natural soil, sand tailings, or mine waste	Sand tailings or mine waste if production rates are sufficient, or natural soil	Sand tailings or mine waste if production rates are sufficient, or natural soil
Relative Embankment Cost	High	Low	High	Moderate

Source: [Vick1983]

BIBLIOGRAPHY

- **Planning, Design, and Analysis of Tailings Dams**, by Steven G.Vick, John Wiley & Sons, New York, 1983, 369 p., ISBN 0-471-89829-5

[The textbook on the subject! A reprint was published in 1990 by BiTech Publishers Ltd., Richmond B.C., Canada (ISBN 0-921095-12-0)

- **Technical Report: Design and Evaluation of Tailings Dams**, U.S.EPA Office of Solid Waste, EPA/530-R-94-038, NTIS/PB94-201845, August 1994, 69 p.

[Provides overview of various methods used to dispose tailings and types of impoundments used. Describes basic concepts to design impoundments including site-specific variables of concern. Discusses embankment stability and water management. Includes a case study on a lined tailings impoundment. The report relies on Vick's book (see above). Be careful: Figures 8-11 are mixed up!] http://www.epa.gov/epaoswer/other/mining/techdocs/tailings.pdf

- **Seminar on SAFE TAILINGS DAM CONSTRUCTIONS, Gällivare, 20-21 September 2001, Technical Papers**. Swedish Mining Association, Naturvårdsverket, EUROPEAN COMMISSION
  Proceedings of the Workshop on Risk Assessment and Contingency Planning in the Management of Mine Tailings, Buenos Aires, Argentina November 5-6, 1998. ICMM, Ottawa, Ont., 1998, 314. http://www.icmm.com/html/pubs_pubs_detail.php?id=12
- **Proceedings of the International Workshop on Managing the Risks of Tailings Disposal**, Stockholm, Sweden, May 22-23, 1997. ICMM, Ottawa, Ont., 1997, 264. http://www.icmm.com/html/pubs_pubs_detail.php?id=21
- **Dynamic safety of earth and rockfill dams**. Proceedings of a course, New Delhi, Aug. 1993, T.Ohmachi, J.Kuwano (Eds.), A.A. Balkema, Rotterdam 1994, 160p.
- **International Symposium on Safety and Rehabilitation of Tailings Dams, (Sydney) 23 May 1990**, Vol.1: Presented Papers. http://www.antenna.nl/wise/uranium/mdap.html#ICOLD , http://www.antenna.nl/wise/uranium/mdap.html#ANCOLD, Sydney 1990, 339.
- **Upstream constructed tailings dams - A review of the basics**, by M.P.Davies and T.E.Martin, In: Tailings and Mine Waste '00, Proceedings of the Seventh International Conference on Tailings and Mine Waste '00, Fort Collins, Colorado, USA, 23-26 January 2000, ISBN 90 5809 126 0, Rotterdam/Brookfield 2000, p. 3-15
- **Some considerations in the stability analysis of upstream tailings dams**, by T.E.Martin and E.C.McRoberts, In: Tailings and Mine Waste '99, Proceedings of the Sixth International Conference on Tailings and Mine Waste '99, Fort Collins, Colorado, USA, 24-27 January 1999, ISBN 90 5809 025 6, Rotterdam/Brookfield 1999, p. 287-302
- **Regulatory and technical tailings design considerations in Chile**, by Alan J. Krause. In: Tailings and Mine Waste '97, Proceedings of the Fourth International Conference on Tailings and Mine Waste '97, Fort Collins, Colorado, USA, 13-17 January 1997, ISBN 90 5410 857 6, Rotterdam/Brookfield 1997, p.51-55
- **Dam-break studies for mine tailings impoundments**, by Jey K.Jeyapalan. In: Geotechnical Engineering Program, Civil Engineering Department, Colorado State University (Ed.), Uranium Mill Tailings Management. Proceedings of the Fifth Symposium, December 9-10, 1982, Fort Collins, Colorado 1982, p.39-53
- **Earthquake effects on uranium mill tailings impoundments**, by W.A.Charlie, R.E.Wardwell. In: Geotechnical Engineering Program, Civil Engineering Department, Colorado State University (Ed.), Uranium Mill Tailings Management. Proceedings of a Symposium, November 20,21, 1978 Vol.II, Fort Collins, Colorado 1978, p.69-85
- **Critical parameters for tailings embankments**, by G.B.Baecher, W.A.Marr, J.S.Lin, J.A.Consla. U.S. Bureau of Mines (Ed.), BUMINES-OFR-135-83, 1983

- **Seismic Hazard Analysis of Title II Reclamation Plans**, by D. Bernreuter, E. McDermott, and J. Wagoner; Report prepared by Lawrence Livermore National Laboratory for the U.S. Nuclear Regulatory Commission, UCRL-ID-121733, 1995, 145 p.
- **Recommendations Regarding Seismic Design Standards for Uranium Mill Tailings Sites in Wyoming**, by James C. Case, Hazards Report 96-1, Wyoming State Geological Survey, Laramie, Wyoming, February 28, 1996, 9p.
- **Mine and Industrial Tailings Dams and Dumps - Bibliography**, Bulletin 44a, International Commission on Large Dams, 1982- 1989; 290 pages.
- **Tailings Dams Safety - Guidelines**, Bulletin 74, International Commission on Large Dams, 1989; 108 pages bilingual (French/English).

[This Bulletin examines tailings dam safety in terms of design, construction, operation and rehabilitation. These are more complex than with conventional earth dams. Appendices deal with environmental safety and recommend legal requirements for these structures]

- **Tailings Dams - Design of drainage**, Bulletin 97, International Commission on Large Dams, 1994; 120 pages bilingual (French/English).
- **Tailings Dams and Seismicity: Review and Recommendations**, Bulletin 98, International Commission on Large Dams, 1995; 60 pages bilingual (French/English).

[According to ICOLD, almost 200 tailings dams "have failed during earthquakes, releasing liquefied tailings that have led to serious damage and loss of life...Tailings dams are very susceptible to earthquake damage." The brochure explores reasons for these failures and suggests solutions to strengthen current dams and build more stable ones. Aspects covered: "Seismic performance; seismicity assessment; geotechnical evaluation; design and construction; seismic stability analysis; and remedial measures to improve safety."]

- **Tailings Dams. Transport, Placement, Decantation - Review and Recommendations**, Bulletin 101, International Commission on Large Dams, 1995, 97p.
- **Tailings Dams and Environment: Review and Recommendations**, Bulletin 103, International Commission on Large Dams, Paris 1996, 103 pages
- **A guide to tailings dams and impoundments: design, construction, use and rehabilitation**, Bull. 106, International Commission on Large Dams, Paris, 1996, 239 p.
- **Design, Construction, and Inspection of Embankment Retention Systems for Uranium Mills**, Regulatory Guide 3.11, U.S. NRC, Dec. 1977, 10 p.
  Full text available through ADAMS, Accession No. ML003740223 (1M TIFF)
- **Operational Inspection and Surveillance of Embankment Retention Systems for Uranium Mill Tailings**, Regulatory Guide 3.11.1, U.S. NRC, Oct. 1980, 8 p.
  Full text available through ADAMS, Accession No. ML003740229 (0.6M TIFF)
- **International Commission on Large Dams -** http://www.icold-cigb.net/
  Commission Internationale des Grands Barrages, 151, boulevard Haussmann
  75008 Paris, France, Tel: +33-1-40425438, Fax: +33-1-40426071
- **United States Society on Dams -** http://www.ussdams.org/
  (formerly United States Committee on Large Dams - USCOLD)
  http://www.ussdams.org/c_tail.html
- **Australian National Committee on Large Dams -** http://www.ancold.org.au/
- **Canadian Dam Association -** http://www.cda.ca/
- http://www.tailings.info