STATE OF NEW MEXICO
BEFORE THE WATER QUALITY CONTROL COMMISSION

| | |
|---|---|
| In the Matter of: PROPOSED AMENDMENT TO 20.6.2 NMAC (Copper Rule) | No. WQCC 12-01(R) |

# EXHIBIT SCOTT – D-27

Information Circular 8755

# Design Guide for Metal and Nonmetal Tailings Disposal

By Roy L. Soderberg and Richard A. Busch

UNITED STATES DEPARTMENT OF THE INTERIOR
Cecil D. Andrus, Secretary

BUREAU OF MINES

# DESIGN GUIDE FOR METAL AND NONMETAL TAILINGS DISPOSAL

by

Roy L. Soderberg[1] and Richard A. Busch[2]

## ABSTRACT

The Bureau of Mines has conducted substantial research on the design, construction, and operation of metal and nonmetal tailings ponds. This design guide, like related Bureau publications that preceded it, is produced to assist the industry in the management of mill tailings disposal. It covers the site selection, sampling, laboratory testing, design, construction, operation, and inspection of tailings embankments. The effects of environment, topography, and hydrogeology are also included, and various methods of stability analysis and factors affecting stability are reviewed. Because of the diversity of problems encountered in tailings embankments, specific solutions are not intended. The guide is, however, a useful checklist for designers, operators, and inspectors of this type of structure.

## INTRODUCTION

This tailings disposal design guide has been prepared by the Bureau of Mines especially for those mining engineers and Government officials responsible for the design, construction, operation, and inspection of mine tailings ponds. These design recommendations are intended to deal specifically with waste from metal and nonmetal ores; however, many of the points discussed are applicable to coal waste embankments, dry mine waste piles, leach dumps, and strip and placer operations which are not specifically covered in this report.

The mining and processing of low-grade metallic ores results in large quantities of waste which leave the plant as a slurry with a 30- to 50-percent pulp density containing as much as 30 to 80 percent material of minus 200-mesh size. This slurry is retained in the tailings ponds, allowing the solids to settle out. The decant water may be recycled or allowed to discharge into a watercourse. Mining operations of 30,000 to 100,000 tons per day are not uncommon with 95+ percent being waste which has to be stored in tailings ponds. The size of these ponds has increased tremendously in the last 10 years; for

[1]Mining engineer.
[2]Civil engineer; associate professor of civil engineering, Gonzaga University, Spokane, Wash.
Both authors are with the Spokane Mining Research Center, Bureau of Mines, Spokane, Wash.

example, in 1938, 1 ton of ore produced 27 pounds of copper; 1947--18 pounds; 1960--14.4 pounds; and 1971--11 pounds. This trend will probably continue, but at a reduced rate. The disposal problem will get worse in the future as larger tonnages are milled and land becomes more costly. The height of the dams will have to be increased, compounding the stability problems.

Research has been conducted on tailings embankments in mountainous areas where long winters with snow and freezing weather are major obstacles and in desert areas where the main problems are seepage into the ground water, dust, and water conservation.

Previous Bureau publications have dealt with various phases of tailings disposal, including design and operation, stability analysis, and seepage (30-33).[3] This report presents additional information on these subjects as well as the newest techniques for reducing seepage into the ground water and for improving the stability and safety of the embankments.

## ACKNOWLEDGMENTS

The authors are grateful to American Smelting and Refining Co. (ASARCO) for allowing research to be conducted on various properties and for its assistance in this work, and to other U.S. mining companies for allowing Bureau personnel to inspect and study their operations. We are also indebted to the following personnel of the Bureau's Spokane Mining Research Center: C. D. Kealy and M. McDonald for technical assistance on soil mechanics and computer output, and L. Atkins, R. Carnes, and D. McKenzie for the laboratory test work.

## BACKGROUND INFORMATION

The prime purpose of the design guide is to outline the criteria relating to waste disposal, some of the problems that will be encountered, and how to solve them. The guide includes explicit details of site investigation, design requirements and specifications, construction techniques, inspection procedures, and detailed investigations including sampling and testing to check the stability of present and future embankments by use of the computer. It is imperative that the design and operation of waste sites be conducted under the direct supervision of engineers who are competent in the fields of waste disposal, construction, soil mechanics, geology, hydrology, and hydraulics.

### Tailings Ponds

As used in this guide, tailings ponds comprise embankments placed on the ground surface that are required to retain slurries of waste and water; they are constructed from tailings, borrow material, or some of each. Some mines use deslimed tailings for underground fill, leaving only the finer material to be impounded on the surface. The materials range from chemically stable quartz to unstable feldspars which can alter to micrometer-size clay.

---

[3]Underlined numbers in parentheses refer to items in the bibliography preceding the appendixes.

An adequate or satisfactory tailings embankment is defined as one that has a good factor of safety, will retain solids, and will control the liquid waste. Prevention of pollution by both solids and liquid must be incorporated in the design plans, together with shapes and stable slopes that will enhance rehabilitation of the area after it has been abandoned.

### Function of Tailings Ponds

The main function of a mine tailings pond is to store solids permanently and to retain water temporarily. The length of time that water must be retained ranges from a few days to months, depending on gradation, mineralogy, etc. When clarified, the water can be reclaimed for plant use or discharged into the drainage.

When the water contains a serious pollutant, the tailings dam must be designed to retain the water for longer periods until the harmful chemicals have degraded or until the water evaporates. A completely closed system is preferred in all such cases, not only for conservation of water, but as a necessity to prevent the pollutant from being discharged. The seepage water from this type of dam must be controlled, treated, and pumped back to the mill for reuse.

## BASIC CONSIDERATIONS

Economics continue to be of prime importance in the design of tailings embankments, including site selection, pumping requirements, length of pipe line, and capital versus operating cost. The annual tonnage versus site acreage, physical properties of tailings, type of embankment, method of waste disposal, availability of construction materials, climate, terrain, hydrology, geology, and nature of the foundation at alternative sites are all important factors. The consequences of failure should be fully considered in establishing the factor of safety (FS) of the embankment design. Embankments in seismically active areas should undergo dynamic analysis to eliminate the possibility of liquefaction from earthquake shock. Embankments in remote areas can have a lower FS than needed in urban areas. Operating costs for tailings disposal can be a big item in a mining operation, and much thought should go into the study of capital versus operating cost. In some cases, the plan with the cheapest capital cost can be the most expensive when the operating cost is added, and vice versa. Probably the cheapest operation possible would be one where a few water-type dams could be constructed to enclose a large area, allowing the operator to merely dump the tailings; this would completely eliminate operating labor except for pump operation and periodic inspections.

### Daily Tonnage

Operation of porphyry copper, taconite, and pebble phosphate mines can more easily anticipate the ultimate area needed for tailings disposal for the life of the deposit than can operation of underground deep-vein mines. These surface deposits are generally well defined with known ore reserves for a given number of years. Knowing this and the anticipated daily tonnage, definite plans for a tailings disposal area can be made. Any planned expansion should be considered at the same time, keeping approximately 35 acres per

1,000 tons of mill production for metal mines, preferably in two separate areas. Taconite operations require about the same acreage per 1,000 tons of waste produced. Under special conditions, such as single-point discharge into large areas where cheap land is available and other factors are favorable, the area per 1,000 tons of waste could go up to two to three times this, but observation of well-engineered taconite tailings areas indicates that 35 acres per 1,000 tons is about optimum where discharge pipelines surround the area. Phosphate mines in flat terrain will require nearly an acre of settling pond per acre of mined land until some improvement in settling rate can be achieved. Because of the fineness of the material and the low pulp density, it is generally deposited at a single point at a time.

## Size of Tailings Area

The size of the tailings embankment necessary for each 1,000 tons of milling capacity for a safe and efficient operation is governed to some extent by the size of the grind, but mostly by the terrain within the tailings area. A relatively level area of a wide, open valley is an ideal site because of the large volume of tailings placed per foot of elevation rise. A starter dam constructed from borrow material is a very important part of the entire impoundment. The purpose of this dam is to contain the sand and provide a pond large enough to insure sufficient water clarification at the start of operations. The steeper the terrain within the embankment area, the higher the starter dam must be to supply the storage necessary for the sand and water until the embankment can be raised with the beach sand. It is far better to make the starter dam a bit higher than required because of the unknown factors at startup of an impoundment. These unknowns are (1) the efficiency of segregation of the sand and slime on the beach, (2) the angle of the beach area, and (3) most important, the retention time in the pond to get clean water. A capacity curve plotting the volume against elevation should be made, as well as a time-capacity curve to get the elevation rise per year through the life of the impoundment (fig. 1).

Where the maximum annual rise is limited to less than 8 feet per year, the active disposal area must be at least 20 acres per 1,000 tons of daily capacity. Operating at this upper limit of rise per year for continuous operation might be safe, but this depends on the grind, pulp density, and type of material being impounded. From an operating and safety point of view, a figure of 30 acres per 1,000 tons of daily capacity is much better for the <u>lower</u> limit of a mature pond. If the site is on a hillside, the startup time is most critical because the area of active storage is small. There is no established rate that an embankment can be raised, but for a given material, gradation, and pulp density there is a definite maximum rate of rise above which stability becomes a problem. If the tailings cannot drain as fast as they are placed in the pond, the phreatic surface rises and comes out the face above the toe dam. When this occurs, seepage and piping take place, lowering the safety factor to the danger point. Possible solutions are to allow time for drainage and to place a filter and rock surcharge on the toe. A rapid annual rise is undesirable because the material does not have time to properly drain, consolidate, and stabilize, nor is there time to raise the peripheral dam.

Sands and gravels are relatively incompressible, and their shear strength is primarily frictional with no cohesion. Here again, the density, gradation, and particle shape determine their behavior. Loose, fine sand acts the same as the same gradation material in mine tailings. If it is saturated and below the critical density, it is subject to liquefaction under shock load. Silts develop strength from either friction or cohesion, depending on density, gradation, and moisture content.

Clay in the foundation may cause embankment settlement and instability. As the embankment rises, the clay may consolidate and gain shear strength. Uncompacted clays in waste piles saturate and swell, reducing their shear strength to almost zero. The finer portions of tailing from metal mines act as clays. The entire output of some mines is mudstone or clay and requires specially designed dams to contain it. Phosphate slimes are also a special case because of the fineness of the clay and the pulp density of the material being impounded.

## Safety Factor

The index of stability with respect to a sudden failure is known as the factor of safety (FS) of the slope. In the most general terms, this may be defined as the ratio of the potential resisting forces to the forces tending to cause movement. The factor of safety may also be defined as that factor by which the shear strength parameters must be divided ($C'/FS$ and $\phi'/FS$) to bring the potential sliding mass into a state of limiting equilibrium. The stress-strain characteristics of most soils are such that relatively large plastic strains may occur as the applied shearing stresses approach the shear strength of the material. Thus, a slope which is on the verge of failure has a factor of safety of 1.0, but in the design the FS must be greater than 1.0 so that the strains will not exceed tolerable limits, and to allow for differences between the pore water pressures and the shear strength parameters assumed in the design and those that actually exist within the slope. The factor of safety of tailings embankments has not yet been determined by law but will very likely be set at 1.5 or greater. Each embankment must be considered on its own merit, based on the following criteria:

1. Location relative to population centers.
2. Total mass (volume and length of life).
3. Rainfall in the area and drainage into the embankment.
4. Mineralogy.
5. Type of terrain.

In other words, a tailings pond within a city or beside a main road or railroad should have a static factor of safety of 1.5, while one in a remote area many miles from civilization would be considered very safe with 1.3. The dynamic factor of safety is generally less, as indicated by a modified Bishop

247-978 O - 77 - 7