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-31

Planning, Design, and Analysis of Tailings Dams

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Water-Retention Type Dams

Water-retention type dams for tailings disposal are constructed to their full height prior to the beginning of discharge into the impoundment. As implied by their name, water-retention type dams used for tailings disposal differ little from conventional water storage structures in appearance, design, or construction. Fill usually consists of native soil borrow of various types. Typical internal zoning, such as that illustrated in Figure 3.1, includes an impervious core, drainage zones, appropriate filters, and upstream riprap. Design of filters, internal seepage control, and slopes is according to conventional earth dam technology. Upstream slopes of tailings storage dams, however, do not experience rapid drawdown and as a result can often be steeper than those of their conventional water storage counterparts.

Water-retention type dams are best suited to tailings impoundments with high water storage requirements. Examples include impoundments with large storm runoff inputs or situations where mill process constraints prevent recirculation of discharged mill effluent and require large water storage volumes or evaporation areas.

Raised Embankments

Surface impoundment structures most commonly consist of raised embankments, which differ from conventional water-retention type structures in that construction of the embankment is staged over the life of the impoundment. Raised embankments begin initially with a *starter dike* constructed usually of natural soil borrow and sized to impound often the initial two to three years' mill tailings output plus appropriate allowances for storage of flood inflows. Subsequent raises of the embankment are scheduled to keep pace with the rising elevation of the tailings and floodwater storage allowance in the impoundment. Embankment raises may be constructed using a wide range of materials, including natural borrow soils, pit mine waste, underground development muck, hydraulically deposited tailings, or cycloned sand tailings.

The advantages of raised embankments are significant. First, because construction expenditures are distributed over the life of the impoundment, initial project development costs are reduced to those necessary for construction of the starter dike. Spacing expenditures over a longer time results in a lower discounted total cost and produces cash-flow benefits that are often important in financial considerations related to mine startup.

Also, because the total volume of fill required for the ultimate embankment need not be available initially, there can be much more flexibility in the selection of materials for embankment construction. Mine waste rock or sand tailings can provide ideal construction materials if dam raising can be paced to their production rates during mining or milling. In some cases where suitable natural soils are not available, the flexibility in use of mine

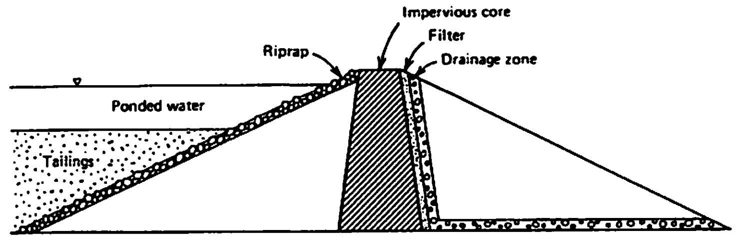

Figure 3.1 Water-retention type dam for tailings storage.

waste materials afforded by raised embankments becomes essential. Even where natural soils are readily available, waste rock, for example, must be disposed of in any event. If haul distances to the tailings embankment are not excessive, these materials provide essentially "free" dam fill, except for the additional cost associated with compaction.

Unlike water-retention type structures built initially to completion, construction of a raised embankment becomes the responsibility of the mine operator, whether performed using mine staff and equipment or by an independent contractor. Considerably more planning effort and attention to scheduling is required to raise the dam many times during the life of the operation.

Raised embankments may assume many configurations, each with unique characteristics, requirements, advantages, and pitfalls. Raised embankments, regardless of the type of material used in their construction, fall generally into three classes: upstream, downstream, and centerline. These designations refer to the direction in which the embankment crest moves in relation to its initial starter dike position as the embankment increases in height.

Upstream Method

The upstream raising method is shown in Figure 3.2. Initially a starter dike is constructed, and tailings are discharged peripherally from its crest to form a beach, as in Figure 3.2a. The beach then becomes the foundation for a second perimeter dike, as shown in Figure 3.2b. This process continues as the embankment increases in height.

Central to the application of the upstream method is that the tailings form a reasonably competent beach for support of the perimeter dikes. As a general rule, no less than 40–60% sand in the discharged whole tailings is necessary. This usually precludes use of the upstream method for tailings in the *soft-rock* or *fine* categories defined in Chapter 1, or when the sand fraction is removed from the whole tailings for use as underground mine backfill. The major advantages of the upstream method are cost and simplic-

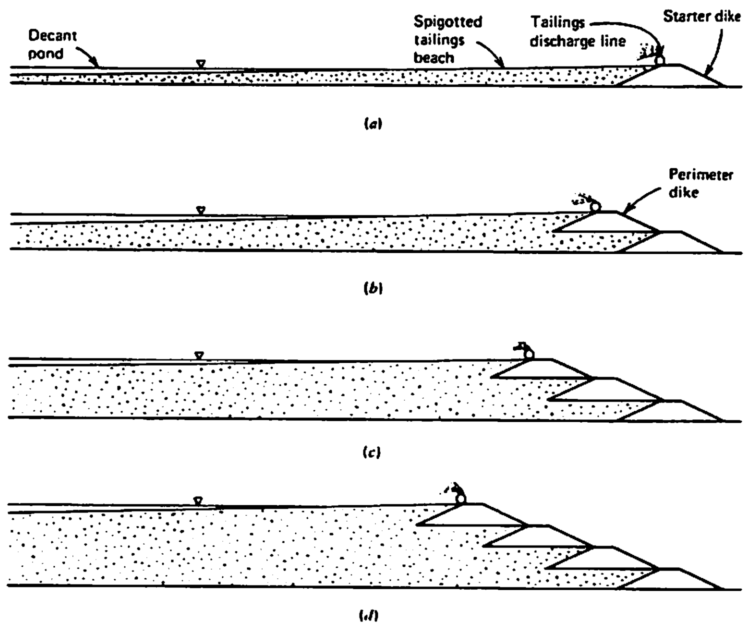

Figure 3.2 Sequential raising, upstream embankment.

ity. Only minimal volumes of mechanically placed fill are necessary for construction of the perimeter dikes, and large embankment heights can be attained at very low cost. Construction of the perimeter dikes is a simple and ongoing operation that can be routinely performed with minimal equipment and personnel. Beach sand tailings often provide a convenient source of fill for perimeter dikes, with excavation from the beach and placement by either dragline or bulldozer.

Use of the upstream raising method, however, is limited to very specific conditions and incorporates a number of inherent disadvantages. Factors that constrain the application of the upstream method include phreatic surface control, water storage capacity, and seismic liquefaction susceptibility.

The location of the phreatic surface is a critical element in determining embankment stability. For upstream embankments constructed by tailings spigotting, there are few structural measures for control of the phreatic surface within the embankment. Figure 3.3 shows that the most important factors influencing the phreatic surface location are the permeability of the foundation relative to the tailings, the degree of grain-size segregation and lateral permeability variation within the deposit, and the location of the

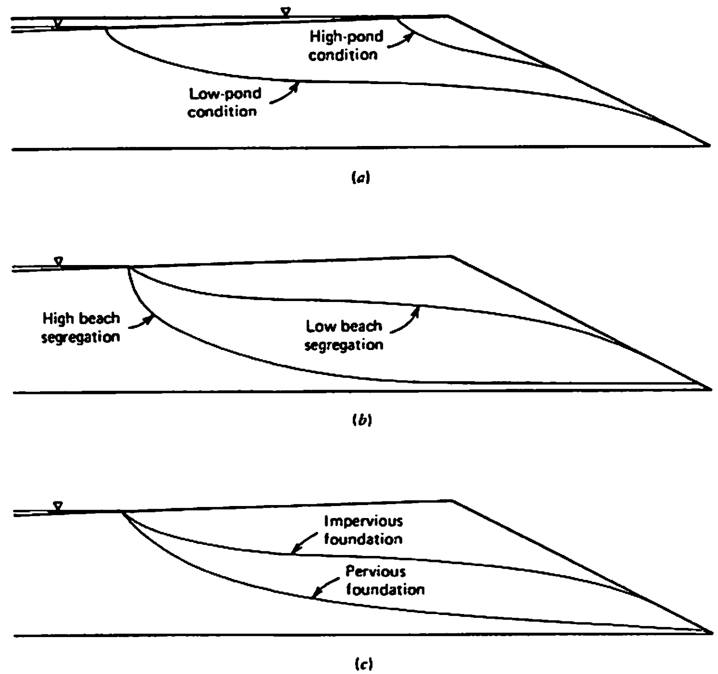

Figure 3.3 Factors influencing phreatic surface location for upstream embankments. (*a*) Effect of pond water location. (*b*) Effect of beach grain-size segregation and lateral permeability variation. (*c*) Effect of foundation permeability.

ponded water relative to the embankment crest. Although cycloning can be used to promote segregation of sands and slimes within the deposit and such measures as underdrains can be used to have the effect of increasing foundation permeability, pond water location is the only factor influencing the phreatic surface that can be controlled during operation.

As shown in Figure 3.3a, pond water encroachment on the tailings beach produces very high phreatic conditions near the embankment face, which endanger stability. In extreme cases, overtopping and consequent embankment breaching result. Many if not most failures of upstream embankments can be attributed to inadequate separation distance between the decant pond and the embankment crest. Ponded water can be pushed back from the embankment crest during operation by proper tailings spigotting and decant procedures. Increase in decanting rates lowers the pond elevation and increases the pond–crest separation distance. Similarly, increased tailings spigotting at critical areas of encroachment can be used to push the water

The type of embankment selected must be compatible with constraints imposed by these factors.

Integrally tied to the selection of embankment type are siting and layout considerations. As discussed at length in Chapter 5, site topography, hydrology, and geology dictate the configuration of both the impoundment and the embankment required to confine it. Layout of the embankment may be in ring dike, cross-valley, sidehill, or valley-bottom configuration. For any of these options, the impoundment may be developed as a single unit or in multiple-segment form.

Having established the preferred disposal method, embankment type, site, and layout, the stage is set for consideration of specific factors that affect design of the embankment itself. The purpose of this chapter is to explore the various issues in tailings embankment design. "Design" in the context of this chapter refers primarily to selection of materials and their internal arrangement or zoning within the embankment section, as well as accounting for special foundation conditions that may influence the performance of the structure. Principles developed in this chapter will result in development of a detailed internal configuration and raising plan for the embankment. They stop short of embankment analysis, various forms of which are considered in subsequent chapters.

CONTROL OF PHREATIC SURFACE

The location of the phreatic surface, or internal water level, within an embankment exerts a fundamental influence on its behavior, and control of the phreatic surface is of primary importance in embankment design. The phreatic level governs to a large degree the overall stability of the embankment under both static and seismic loading conditions, in addition to influencing the susceptibility of the embankment to seepage-induced failure.

The objective of prime importance is to keep the phreatic surface as low as possible in the vicinity of the embankment face. To the extent that the arrangement of materials of differing permeability within the embankment governs internal seepage patterns, control of the phreatic surface dictates the types of materials required for construction and their configuration in internal zones. A general principle that guides embankment design in relation to phreatic surface control is that permeability of various internal zones should increase in the direction of seepage flow. As permeability increases, the phreatic surface is progressively lowered, and ideally the most pervious available material should be located at or beneath the embankment face.

This principle is illustrated in Figure 7.1. Figure 7.1a shows an idealized upstream embankment in which permeability increases in successive zones in the direction of seepage flow, from low-permeability slimes near the decant pond to high-permeability sands at the embankment face. In this case, the phreatic surface is reasonably low near the face, and seepage breakout

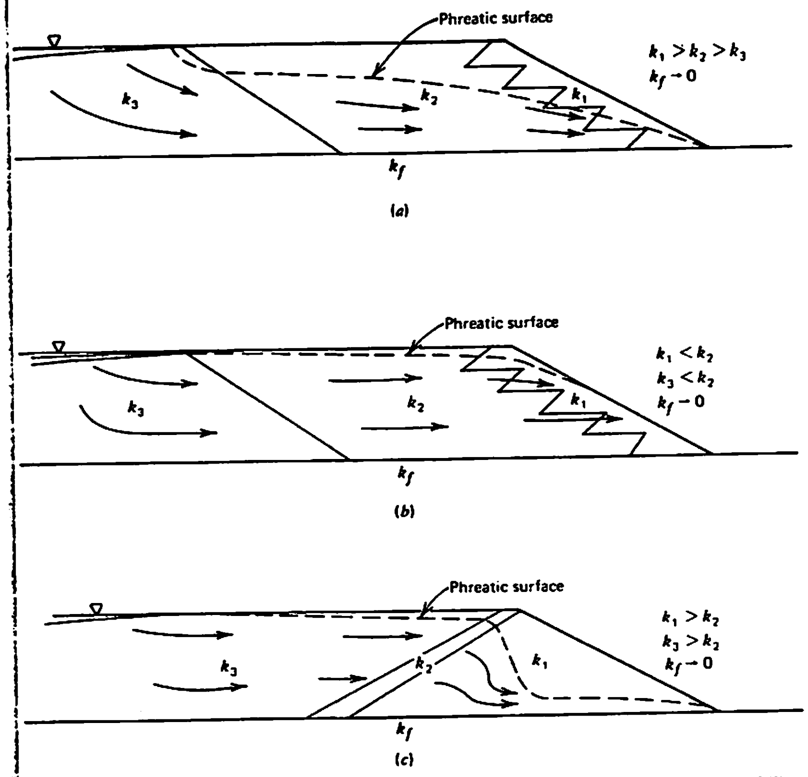

Figure 7.1 Effect of internal zoning on phreatic surface. (*a*) Proper internal permeability configuration for control of phreatic surface. Arrows indicate flow direction. (*b*) Seepage blocked by low-permeability material at embankment face, producing high phreatic surface. (*c*) Seepage restricted by upstream core and drained by downstream pervious zone to produce good phreatic surface control.

on the face itself, which could induce dangerous erosion and slumping, is avoided.

Figure 7.1b shows the same case, except with a low-permeability zone at the face, such as might result from perimeter dikes constructed of clayey natural soils. Here the low-permeability zone impedes drainage and results in an elevated phreatic surface that breaks out high on the embankment face, producing conditions conducive to both mass instability and such seepage-related problems as piping and erosional sloughing.

The principle of increasing permeability in the direction of seepage flow applies in a strict sense only to materials near the embankment face. Figure