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Dewatering Tailings Impoundments: Interior Drains

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SYNOPSIS

For the design of a new uranium tailings impoundment in the western United States, it was proposed that an interior drainage system be considered to economically and reliably minimize potential short- and long-term environmental impacts. The objectives were to decrease the effective hydraulic head on the clay liner, to dewater and stabilize the tailings, and to increase the amount of water recycled to the mill. In addition, desaturation of the impoundment would induce capillary pressure (negative porewater pressure), further reducing the potential movement of dissolved pollutants. This paper presents saturated and unsaturated seepage principles and reviews the concept, criteria and design of the various interior drainage systems considered.

INTRODUCTION

Uranium mills typically produce slurried tailings which are hydraulically deposited in a tailings impoundment. The slurried tailings contain about 25% solids (75% liquids) by volume and have a low pH. For lined impoundments, Staub (1978) estimates that after decanting over half of the input water is stored in the tailings. As long as the impounded tailings remain in a loose and saturated state, potential hazards exist that include

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potential for short- and long-term seepage from the impoundments and the potential for large scale release and movement of liquified tailings. The breach of an earthen dam on July 16, 1979, at Church Rock, New Mexico, and the subsequent release of 100 million gallons of water and slurried uranium tailings, underlines the potential hazard. If the tailings could be dewatered, the liner's integrity will become less critical, and long-term seepage would be greatly reduced. In addition, the potential for tailings liquefaction from an embankment failure or earthquake would be greatly reduced (Charlie and Wardwell, 1979). This paper reviews the concept, criteria, and design of various proposed interior drainage systems to dewater the tailings after deposition.

SATURATED AND UNSATURATED SEEPAGE

The use of interior drainage for tailings impoundments, whether lined or unlined, involves little in the way of dramatic new concepts, technology or mathematical analysis. Control of hydraulic conditions in such deposits involves the adaptation of well-developed principles and practices from the fields of groundwater, geotechnical and agricultural engineering. For more detailed information on saturated and unsaturated flow concepts, the reader is referred to Corey (1977) and McWhorter and Sunada (1977). Particular attention to tailings impoundments is given by McWhorter and Nelson (1979).

Darcy's law is an empirical equation for macroscopic volume flux in porous media which is valid for both saturated and unsaturated conditions and can be written

$$Q = k \ i \ A$$

where Q is the volume flux (L^3/T), k is the permeability of the porous media (L/T), i is the hydraulic gradient and A is cross sectional area normal to the flow direction. This relationship shows that the fluid volume flux rate is directly proportional to the hydraulic gradient. If a tailings impoundment is saturated, permeability is a constant, k_s. If desaturation due to drainage occurs, some of the porewater is displaced by air, negative porewater pressures (capillary pressures) occur, and the permeability decreases. Unsaturated permeability is always less than the saturated permeability and has been expressed (Corey, 1977) as an exponential function of the effective Saturation, S_e,

$$k_e = k_s \ S_e$$

where k_e is the effective, unsaturated permeability, S_e is the effective saturation and is an empirical coefficient. Thus, the volume flux of fluids in an unsaturated condition is considerably lower than the flux under saturated conditions. In addition, as shown in Figs. 1 and 2, the empirical coefficient, , varies depending on the type of soil. Coarse soils, which have high saturated permeabilities, drain quickly but may have lower unsaturated permeabilities at high capillary pressures than finer soils. This relationship can be used to advantage in controlling flow in segregated or layered sand-slime impoundments because a "capillary break" will occur.

Fig. 3 shows the equilibrium case where the soil has drained and flow has ceased. Once the soil becomes desaturated, capillary pressure develops, i.e. the pressure head becomes negative. The suction is dependent upon the distribution of pores in the material and the direction from which equilibrium was reached. Note that the soil is saturated for some distance above the water table in the capillary fringe, a zone where the saturated permeability value still holds under negative pressure. This zone varies from a few millimeters for gravels to tens of meters for some clays.

The maximum drainage situation is the condition of "residual saturation," also called field capacity in agricultural usage. Note that in Fig. 2 for both materials, the water content at high suctions asymptotically approaches minimum values. At this level, the water is "trapped" and additional gravity drainage is negligible. Any further drainage will be due to inputs of external energy such as evaporation, plant uptake, infiltration, or chemical concentration or vapor pressure gradients.

A condition of particular interest for tailings deposits is that of layered soil analogous to interbedded sands and slimes. A discontinuity occurs at the junction of the layers. This can either be an advantage or a liability in tailings applications. The concept of a capillary break for vertical flows is illustrated in Fig. 4. The capillary pressures will match across the interface but the effective saturations and permeabilities of the two materials vary. The unsaturated permeability of the coarse material will be lower at high suction values. If allowed to become saturated, however, the coarse material would eventually increase permeability, decrease its head loss, and become a drain in the accustomed manner for positive pressure applications such as dams, highways, and field subdrains.

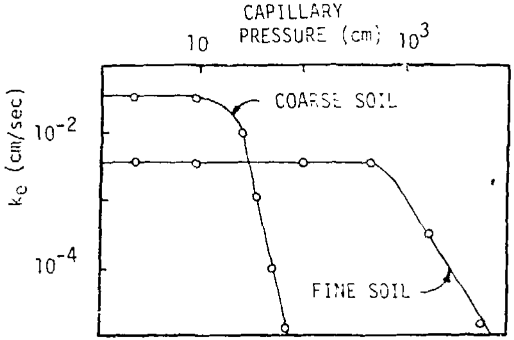

Figure 1. Permeability as a function of capillary suction (Corey, 1977).

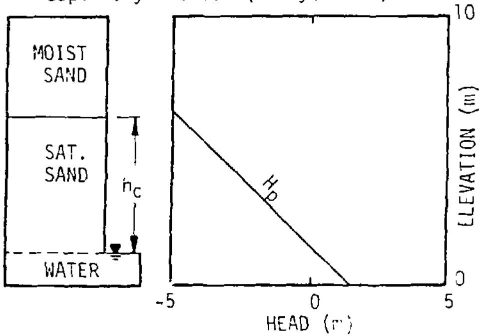

Figure 3. Drained sand column under equilibrium conditions.

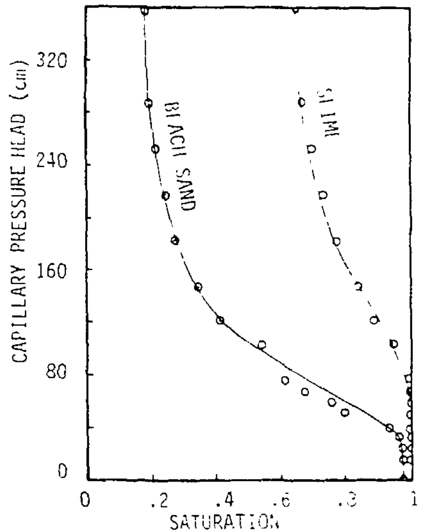

Figure 2. Saturation as a function of capillary suction (Vevera, 1980).

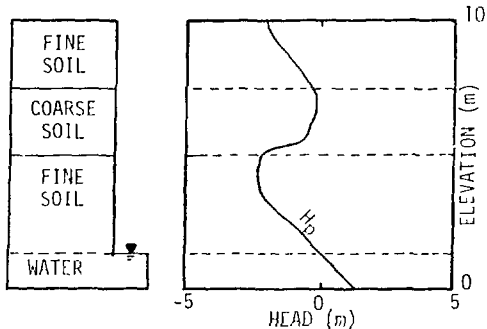

Figure 4. Layered soil column during steady flow conditions.

DESIGN EXAMPLE

For the design of a new uranium tailings impoundment in the western United States, a state-of-the-art interior drainage system was considered. The system was designed to decrease the effective hydraulic head on the clay liner and to dewater *and stabilize the tailings as* rapidly and as thoroughly as possible. The impoundment was designed to store 20 years of tailings output (3×10^6 m^3) from the plant at 750 dry tons per day. The pH of the tailings liquor was estimated as 4 and the water table is more than 30 meters below the bottom of the impoundment. In-situ permeability tests yielded saturated permeabilities of 1×10^{-6} cm/sec to 1×10^{-5} cm/sec for the top 50 meters of the substrate.

Fig. 5 shows an impoundment design without interior drains but utilizing a clay liner to reduce seepage. After deposition, the tailings are saturated and will remain saturated for a considerable length of time. Therefore, a positive hydrostatic pressure exists on the liner. Even if the permeability of the liner is small, some seepage through the liner will occur.

Figs. 6, 7, and 8 show the drainage designs considered to dewater the lined impoundment. Figure 6 shows an impoundment design utilizing finger drains. Finger drains *are* used in the Cotter impoundment in Colorado (Lubina, Hovater and McCready, 1980). Plastic pipes (PVC), protected by aggregate filters and placed above the liner, are designed to ensure a very small hydrostatic water pressure on the liner near the drains. The closer the drain spacing, the lower the hydrostatic water

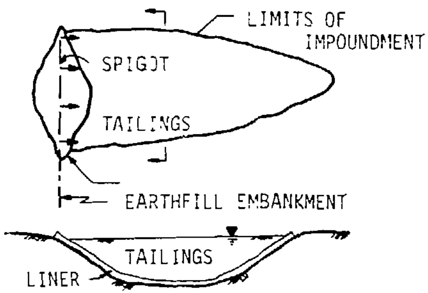

Figure 5. Typical existing impoundment without internal drainage.

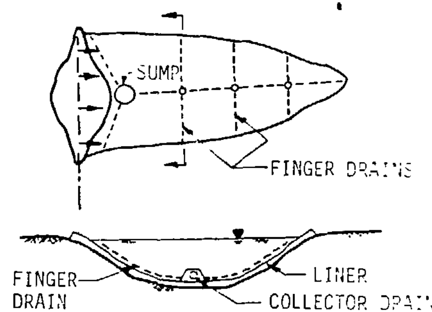

Figure 6. Interior drainage system utilizing finger drains.

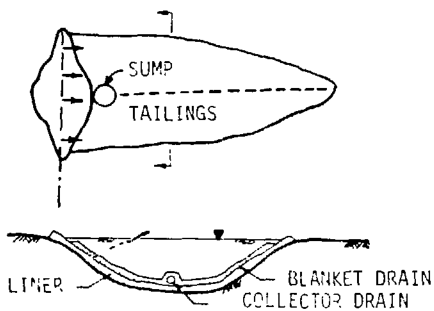

Figure 7. Interior drainage utilizing a blanket drain.

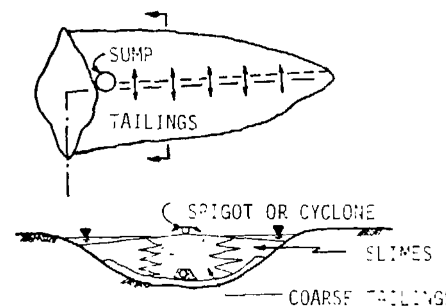

Figure 8. Interior drainage utilizing tailings segregation.

pressure between the drains. Based on the ellipse equation for steady flow to parallel drains with vertical recharge (McWhorter and Sunada, 1977), drain spacing should not exceed 30 meters for the design example.

Fig. 7 is similar to Fig. 6 except a sand and gravel blanket is placed above the liner. This sand and gravel blanket has a high permeability and is used to convey the drainage to a collector pipe. A 1.0 meter thick blanket drain and a center collector pipe would be adequate, provided the maximum flow distance from the collector pipe does not exceed 100 meters. The design shown in Fig. 8 also uses a center collection system protected by filters but does not have a blanket drain. In contrast to the other methods considered, this method deposits the tailings such that the coarse tailings settle out above the drains and the slimes tend to settle out along the sides of the impoundment. This concept is similar to the dewatering method used at Union Carbide's Gas Hill project in Wyoming. The coarse tailings, which drain faster, act as a large vertical drain, collecting both vertical infiltration from the surface and lateral drainage from the slimes. The lateral drainage occurs because horizontal permeabilities in water deposited material are generally higher than vertical permeabilities. Once dewatering has induced unsaturated conditions in the tailings, capillary pressure develops which will further reduce seepage, both out of the impoundment and from the slimes into the coarse tailings.

The final design and actual construction combined all of the drainage concepts discussed above. It was felt that a combination of finger drains, a blanket drain and tailings segregation was more reliable than any of these options individually. Further, a combination of methods was found to be more economical. Because the design was not based entirely on one option, each component could be modified so that the result was a lower total cost. For example, because a blanket drain and tailings segregation are also used, the finger drains can be spaced farther apart. Similarly, since a blanket drain was only one part of the design, supported by finger drains and tailings segregation, local material rather than imported material was used. This resulted in significant cost savings.

Although some water will be decanted or lost by evaporation, the drainage system was designed to handle the total liquid discharge from the mill of 0.5 cubic meters per min. The flow through the tailings impoundment into the drains was estimated using Darcy's law. An average saturated permeability for the tailings of 5×10^{-5}

cm/sec was used and the tailings were assumed to be discharged over an area of 200,000 square meters. For these values and a hydraulic gradient of one, Darcy's law yields 0.6 cubic meters per minute, the volume which will drain through the tailings provided the sub-drain can handle this flow. This is sufficient since the 0.5 cubic meters per minute is the design requirement. If the tailings desaturate, the permeability and flow would be less than the saturated values and the drainage system would still be effective. In addition, upon desaturation of the drain blanket, it would become a capillary break between the tailings and the liner.

SHORT-TERM PERFORMANCE

Internal drainage systems, provided they are designed and built in accordance with good practices, should function for a considerable time with only moderate upkeep and maintenance. However, the pH and dissolved solids in the seepage, and the possible migration of fine tailings into the underdrain system, could reduce the efficiency of the system. Therefore, the discharge from the drainage system should be compared with predicted seepage rates. Seepage should also be monitored for changes with time, and cleanouts should be provided to flush and remove potential silt and mineral deposits from the collection pipes. In addition, a series of piezometers or well points in the pipes, in the filters surrounding the pipes, in the drains, and in the tailings would be useful to determine the effectiveness of the interior dewatering drainage system. If problems develop, this information would be very helpful for proposing modifications. In the design example, deposition of tailings began in 1980 and the drainage system is currently functioning adequately.

LONG-TERM PERFORMANCE

The properties and hence behavior of mill tailings during long-term impoundment can be expected to change. Although the inevitability of these changes is obvious, prediction of the exact nature and rate of change is extremely difficult owing to the large number of variables that interact.

Once an ore and its accompanying gangue minerals are removed from their natural physio-chemical environment, they are likely to be unstable. Processing usually includes the diminution of particle size which increases the materials susceptibility to chemical reaction. In storage, the tailings will undergo changes that emmulate nature's processes of weathering and soil formation and will include changes in composition as well as particle size. As with soil genesis, a conceptual model of long-term talings behavior must include Jenny's (1941) factors of soil formation. These factors are climate, organisms, topography, parent material and time.

Following the passage of time, tailings may be expected to reach an equilibrium with their environment and become stable until one or more of the above factors change. Because those factors of soil formation are not independent variables and because some are not easily quantified, they do not yield simple, unique predictions of the behavior of a material under given conditions. Never-the-less, they do provide valuable guidance in studying and better understanding these natural systems.

The important chemical reactions that must be considered in the design of long-term tailings impoundments include hydrolosis, chelation, oxydation, hydration/dehydration, ion exchange and solution. Clearly, these reactions are capable of changing the engineering properties of the tailings.

Starting with general information relative to the five factors of soil formation, a conceptual model to predict changes in engineering properties can be produced. Owing to the dearth of empirical data, this becomes largely a deductive analysis. As an example, we will consider long-term permeability changes with the design case cited above for a tailings impoundment (as shown in Fig. 7) located more than 30 meters above the water table and in a semi-arid climate. Furthermore, we assume the impoundment functions properly as built, and wish to predict long-term changes in permeability of the tailings and of the material used for the blanket drain. The permeability of these materials is, in large part, a function of the size distribution of the particles. Krumbein and Monk (1942) have investigated the relationship between permeability, uniformity of grain size and mean grain size (Fig. 9). Materials with smaller and more uniform particle sizes exhibit lower permeabilities. Over the long term we can expect a decrease in particle size as well as a decrease in size variability. From any point on the permeability surface shown in Fig. 9, the trend with time will be towards the origin of the graph. Material used for the blanket drain must be chemically more stable than tailings so that it will maintain a higher permeability than the tailings. Furthermore, spe-

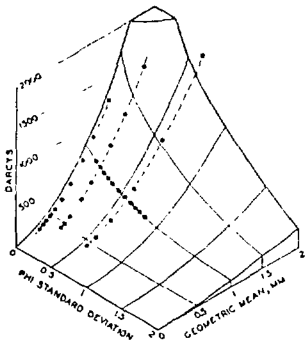

Figure 9. Permeability surface.
(from Krumbein and Monk, 1942)

cial care to avoid preferentially plugging the pores of the drain materials by crystallization of secondary minerals must be taken. One must assume that the pH of tailings and associated fluids will moderate with time and that dissolved species will be precipitated. Long-term planning must accommodate these eventualities.

SUMMARY

An interior drainage system to dewater uranium tailings impoundments possesses several environmental, operational, safety, and economical advantages. Dewatering will minimize the potential for short- and long-term seepage and will minimize the potential for tailings liquefaction. Seepage methods using Darcy's law to predict the flow of tailings liquor through the tailings and into the drainage system were discussed along with the effect of capillary pressure and capillary breaks. Potential for clogging of the drainage system from fine tailings and mineral deposition must be considered in the design. Cleanouts should be provided in the drainage pipes. Design of filters is especially critical since hydraulically deposited tailings leads to segregation of the fine and coarse fractions. To ensure long, trouble-free performance of an interior drainage system, the need for proper design, use of long-life materials, quality of workmanship and inspection, and monitoring of performance cannot be overemphasized.

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