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# The Role of Water in the Failure of Tailings Dams

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## INTRODUCTION

At some of his earliest lectures, the young engineering student learns that hydrostatic pressure exerted by a body of water is proportional to the height of water. With this fundamental knowledge, the engineer is well aware of the significance of impounded water (and porewater) in his design of a tailings retention embankment. As the structures get larger, so the importance of hydro loading increases.

The improved efficiency of modern mining operations and metallurgical processes has resulted in the working of lower grade ores and, at the same time, in an intensification of one of the mill managers' major headaches--the disposal of tailings. As the quantity of tailings grows, the amount of water and fine tailings that must be handled is vastly increased, as is the potential for problems with water and saturated slimes.

In the past, the most common method of tailings dam construction has been to raise the dike with hydraulically placed coarse tailings obtained by gravity segregation or by cycloning. The crest of the dike was usually maintained just above the level of the slimes and pond. Often, this margin does not provide an adequate safety margin against extreme water loading conditions. Most of the newer tailings dams are designed and constructed by adopting techniques used for water retaining embankments; however, many dams that are constructed with hydraulically placed coarse tailings are still being used successfully.

If the ore tailings could be moved by other than hydraulic methods and if the deposit could be located away from stream channels, most of the potential water loading problems in tailings disposal operations would be eliminated; however, economic considerations dictate that these options are generally not available. A vast majority of milling operations require water for processing, and, thus, water serves as an inexpensive transportation medium for the tails in the form of a slurry. When this water is in the tailings disposal area and is supplemented by direct precipitation and surface runoff, many water control problems can develop. When the engineer does not provide for control of the water, the destructive forces are very evident, as shown in Figure 1.

This paper enumerates the more critical water loading conditions to which tailings dams and deposits are subjected. The potential failure modes resulting from these loading conditions are presented.

Figure 1

## DEFINITIONS

### General

In any discussion of the failure of structures, it is desirable (if not necessary) to provide a meaningful definition of failure. The International Commission on Large Dams (ICOLD) performed a study on "Failures and Accidents to Large Dams" in the period from 1965 to 1973(1). The reported incidents were divided into four general categories, namely:

Failures
Accidents
Damage During Construction
Major Repair

Because of the numerous varieties of incidents, these four categories were further subdivided into a total of eight;

Dam Failure - Types 1 and 2,
Dam Accident - Types 1, 2, and 3,
Accident - Reservoir,
Damage During Construction, and
Major Repair.

As is readily apparent from these sub-categories, there is no single definition of failure that applies to accidents, incidents, damage, and repairs. For the purpose of this discussion, failure is defined as collapse of any part of a tailings deposit to a degree that would result in questionable safety, either during continued operation or if use is discontinued.

While tailings dams were not included in the study discussed above, most of the same general categories apply to incidents involving tailings structures. In fact, older tailings dams can be expected to have a much higher rate of incidents because of the lack of engineering and construction control and because of the type of construction (i.e., hydraulic fill).

### Types of Water Loading

The types of water loading to which a tailings dam can be subjected include:

Flood Water
- Rain
- Snowmelt

In Situ Water
- Seepage
- Pore

Through practical experience and applied soil mechanics theories, techniques have been developed to control these water loadings. Properly designed water control systems will, at minimum cost, provide adequate stability of the tailings embankment and control the quantity and quality of water that leaves the disposal area. The decision on the type and extent of control systems will include consideration of environmental requirements, needs of the mill processing operation, and the risk and expense of failures.

Types of Failure

The most common failures, or incidents, to tailings dams that can be attributed to unfavorable water loads are in the form of:

1. Overtopping
2. Sliding
3. Liquefaction
4. Piping
5. Erosion

Some of these incidents will occur quickly with little or no warning (e.g., liquefaction), while in others, the structure will show signs of distress over a significant period of time (gullying, cracking, turbidity, etc.). If the disposal operation has not been banished from thought(2), time will generally be available to provide corrective maintenance. Combinations of these water loadings and incidents can and often do occur; erosion can lead to piping, and sliding can be followed by overtopping.

Overtopping - One of the most common causes of failure is overtopping by floodwaters. Because of the great susceptibility of cohesionless materials to erosion, retaining dikes constructed of coarse tailings must never be overtopped, or breaching and loss of the impounded semi-liquid slimes can be expected. Provisions should be made to pass major floods around a tailings dike. Generally, the problem is of major concern only for cross-valley deposits, where river diversion can be a critical factor in any economic feasibility study of a tailings disposal operation. However, the danger of flooding and overtopping the dikes of a side-hill deposit must also be considered.

Slide - Excess porewater pressures can reduce effective stresses within the tailings and can result in a decrease in shear strength. This reduction in shear strength could cause slope instability problems of many variations from local sloughing of particles at random areas along the face of an embankment to massive circular arc slides. A more detailed discussion of porewater pressures (neutral stresses) is presented in a subsequent section.

Liquefaction - Tailings dams placed by hydraulic methods using the upstream method of construction are particularly susceptible to liquefaction. This is a phenomenon where loose, saturated, fine grained material is subject to a large increase in porewater pressure due to lack of drainage, causing loss of effective stress. Because of their often catastrophic nature, most of the tailings deposit failures that have received publicity have been those resulting from liquefaction. Such failures occur instantaneously with no warning. They may be triggered by seismic or other vibrations, foundation spreading, or some form of dike collapse. Hazen (3) provides a clear description of the physical causes of liquefaction of sand.

Piping - Internal erosion (piping) of an embankment is caused by high seepage gradients within the soils. The potential for piping can be reduced by locating the decant pond as far as possible from the retaining structure and by providing an adequate drainage system.

Erosion - The loss of surface material due to direct rainfall or flowing surface water can result in an erosion failure or incident. In areas of heavy rainfall, some form of protection against erosion is usually required. Since a single storm rarely causes major damage, the problem is generally considered to be one of maintenance; however, if maintenance is neglected, the cumulative effects of intermittent erosion can produce a failure.

## Risk

Because of the limits of knowledge in geotechnical engineering, there is uncertainty involved in the design and construction of earthwork structures. This uncertainty requires that the engineer or mill manager accept a certain amount of risk in the design and operation of the tailings disposal facilities. The degree of risk will depend on the consequences of failure and on the economic factors.

Mining folklore tells us that no tailings dam has ever been completed without at least one failure occurring during deposition. These failures, the term being undefined, could include everything from a slight nonconformity with the design to complete collapse. It is good economic practice in mill management to allow minor maintenance problems such as local sloughing to occur. If occasional problems do not occur, the mill manager is accused of being conservative in his tailings disposal design and lacking fiscal responsibility. However, the potential for major failures that could lead to loss of life or property must be considered in evaluating the risks.

In his paper entitled "Role of the 'Calculated Risk' in Earthwork and Foundation Engineering", Casagrande(4) describes the use of the observational approach in earthwork engineering. He explains that the continuous evaluation of observations and new information while construction is in progress presents the opportunity for reducing uncertainty and for redesigning effectively. His evaluation of the term 'Calculated Risk' suggests two steps:

a) The use of imperfect knowledge, guided by judgment and experience, to estimate the probable ranges for all pertinent quantities that enter into the solution of a problem.

b) The decision on an appropriate margin of safety, or degree of risk, taking into consideration economic factors and the magnitude of losses that would result from failure.

Casagrande presents a series of case histories involving calculated risks. Peck(5), in his discussion of the use of this method in applied soil mechanics, points out its advantages and limitations.

The observational approach is particularly applicable to tailings disposal and specifically in controlling the destructive forces of water. Smith, et al.(6), in their paper "Observational Approach to Tailings Dam Enlargement" provide an example of how the observational approach was used over a period of years for a tailings deposit. They summarize the procedure for application of the approach in the following manner:

1) Sufficient background data are obtained to define the nature and probable range of pertinent engineering variables.

2) Geotechnical analyses are performed, which include consideration of possible extreme conditions.

3) A systematic behavior monitoring program is established to provide a data base for continuing engineering analyses.

4) Alternative designs and standby operational procedures are studied, considering the possible extreme conditions.

5) Design changes are made based on actual conditions encountered.

Mining engineers and mill superintendents have been using the observational approach for many years in planning and constructing their tailings disposal operations. The continued existence of many of the old deposits confirms the success of the techniques used.

Monitoring programs can be very helpful during the construction and operation of tailings dams to evaluate the role of water in the safety of the tailings deposit. Piezometer, observation well, and weir readings are used to monitor pore water pressures within the embankment and quality and quantity of seepage releases. If these observations indicate potential problems that could lead to failure or pollution, the dike design or disposal method can be modified to resolve the problem. This is a simple example of how the observational approach can be used to reduce the calculated risk that mill managers are obligated to take for economical development of tailings disposal operations.

## IN SITU WATER

### General

In situ water consists of seepage and pore water. They represent water forms that affect the soil skeleton and its properties. For this discussion of in situ water, it is assumed that all the voids in the soil skeleton are continuous and filled with water.

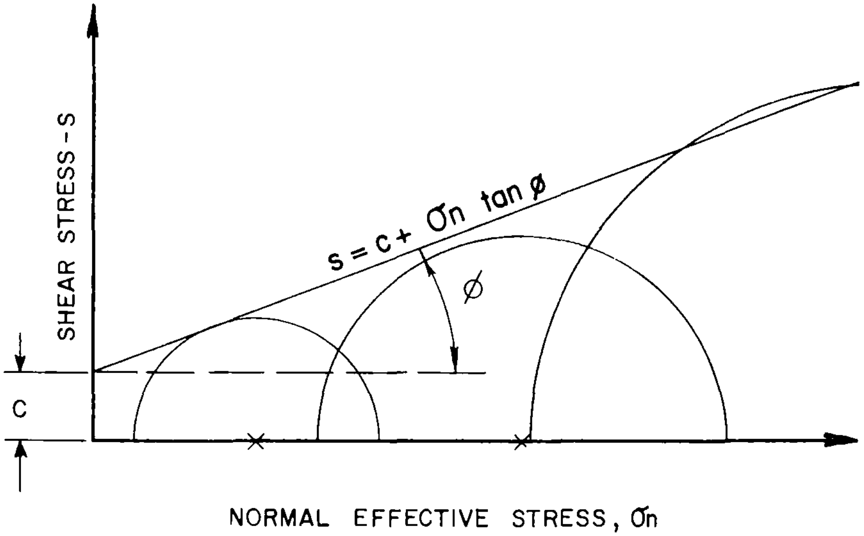
To understand the role of water in the design of tailings dams and the prevention of possible failures, it is desirable to be familiar with: the effect of pore water on the shear strength of soils; the theory of seepage in soils; and the phenomenon of liquefaction.

## Neutral Stresses

Neutral stresses or pore water pressures in a soil are the pressures produced by water load. They are determined from knowledge of static water level or from flow net construction. The total normal stress at any point in a saturated soil consists of two parts: the neutral (pore water pressure) and the effective stress. The effective stress is defined to be the total stress minus the pore water pressure. The effective stress in a soil controls physical properties of the soil skeleton such as compressibility, distortion, and shear strength(7,8). Therefore, every investigation of stability or settlement requires the knowledge of both total and neutral stresses.

The type of soil collapse that most concerns soils engineers and tailings dam designers is shear failure. The shear strength of a soil is determined in the laboratory by applying an axial load to a cylindrical sample in a manner similar to that used to determine the strength of concrete. The most common type of test used to determine shear strength properties is a triaxial compression test. The advantage of this type of test is that it permits the application of the three dimensional stress conditions found in the field to an undisturbed or compacted soil sample and thus makes it possible to study the stress-strain behavior and the ultimate strength under in situ conditions.

It is important that drainage conditions during the tests conform to conditions within the existing soil structure. If a series of tests is made at different confining pressures under drained conditions, the normal effective stress can be plotted against shear stress as shown on the Mohr diagram in Figure 2. The equation $S = C + \sigma \tan\phi$ describes the shear strength of soils. The parameters C and $\phi$ represent cohesion and angle of friction, respectively,



TYPICAL MOHR STRENGTH ENVELOPE
FROM TRIAXIAL COMPRESSION TEST

Figure 2

and are usually almost constant for a given soil within a given range of normal stresses.

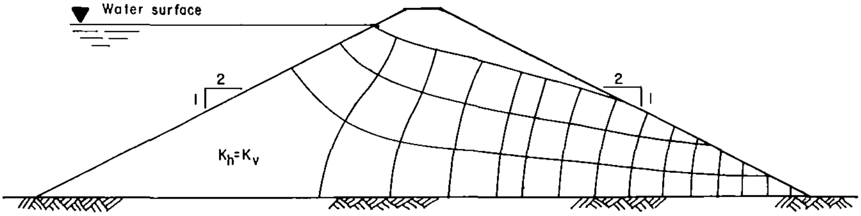
In evaluating the stability of a tailings dam slope, different potential failure surfaces are selected, and the total driving force is compared with the total resisting force along the surface. The driving force is generally obtained from the weight of material within the surface and the resisting force obtained from the shear strength along the surface. The Mohr's envelope is used to determine shear strength once the effective stress is determined by subtracting the neutral stress obtained from a flow net diagram from the total stress. Experience has shown that porewater pressures exert considerable influence on the safety factor agains a sliding failure.

## Seepage Theory

Seepage theory is used in the design of tailings dams and water supply dams to determine the location and magnitude of potential problems resulting from water flowing through the dam or its foundation. These include excess porewater pressure, large hydraulic gradient and high flow quantities. When problem areas are identified, the design can include measures either to control the potential problem or to alleviate it. Uncontrolled seepage may result in piping, slope instability, or release of contaminants.

The flow of water through soils (or tailings) follows Darcy's empirical law, which states that the amount of flow is directly proportional to the hydraulic gradient. Darcy's equation is $Q = kiA$, where Q is seepage quantity, k is the coefficient of permeability, i is the hydraulic gradient, and A is total cross sectional area normal to direction of flow. Cedergren(9) provides a detailed discussion of Darcy's Law and seepage principle.

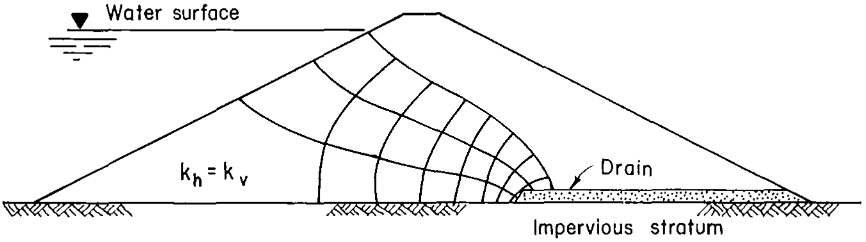
Flow nets are sketches to solve seepage problems in two dimensions. Casagrande(10) presents a method for the construction of flow nets and discusses its theoretical background and practical uses. Basically, the flow net is a graphical solution of the La Place differential equation for steady flow through isotropic soils, which assumes that Darcy's law is valid. Two sets of lines are drawn; these are flow lines and equipotential lines. Flow lines are drawn parallel to the general direction of water flow. Equipotential lines represent contours of equal pressure head, which intersect flow lines perpendicularly. The top flow line defines the phreatic surface. Piezometric pressures at any point can be estimated from the equipotential lines. The flow net (Figure 3) for a homogeneous dam, having no seepage control features and resting on an impervious foundation, shows the phreatic line intersecting the downstream slope. This condition would probably result



FLOW NET – HOMOGENEOUS EARTH DAM ON IMPERVIOUS FOUNDATION

Figure 3

in slope instability and piping problems. The addition of a toe drain or downstream blanket drain would lower the phreatic line and, in the process, would eliminate the potential for piping and slope instability problems, Figures 4 and 5.



FLOW NET - HOMOGENEOUS EARTH DAM WITH BLANKET DRAIN

Figure 4

Figure 5

### Liquefaction

Among the most spectacular, and often most disastrous, types of tailings dike failure is that resulting from liquefaction of the fine particles combined with a breach of the main retaining dike.

The often catastrophic nature of liquefaction failures results from the speed with which they occur and the absence of any warning. The material in an earth structure can be in a metastable state either continuously or periodically over a number of years until, eventually, a random event triggers spontaneous liquefaction. Among the numerous causes of liquefaction that have been found by investigation of previous failures are:

1. Earthquake vibrations.
2. Excess porewater pressures.
3. Large strains in loosely deposted materials.

All of these possibilities are applicable to tailings deposits and must be considered in the design and layout of a disposal area.

The liquefaction susceptibility of tailings deposits is most readily reduced by (i) increasing the in situ densities and (ii) eliminating excess porewater pressures. Mill superintendents are responsible for achieving the minimum requirements of either or both of these in situ material properties by the most economical method. Sound planning, combined with the adoption of relatively inexpensive modifications of disposal techniques during the early stages of an operation, can prevent problems from arising during later operations. Such problems, if allowed to develop, are invariably costly to eliminate.

## SURFACE WATER

### General

The effects of the surface water loading on a tailings deposit have considerable influence on the design and economics of the disposal. By analyzing the hydrology of the disposal location, the need for flood control and erosion control can be assessed. Many options are open to the designer to minimize the effects of potentially destructive surface waters. These options include: the location of tailings deposits in relation to the topography, whether it is a cross-valley, side hill, or flat ground deposit; the size of diversion works and spillway; and the type of erosion control. The tailings disposal operation must be designed to ensure that the retention dike will never be overtopped.

## Hydrology

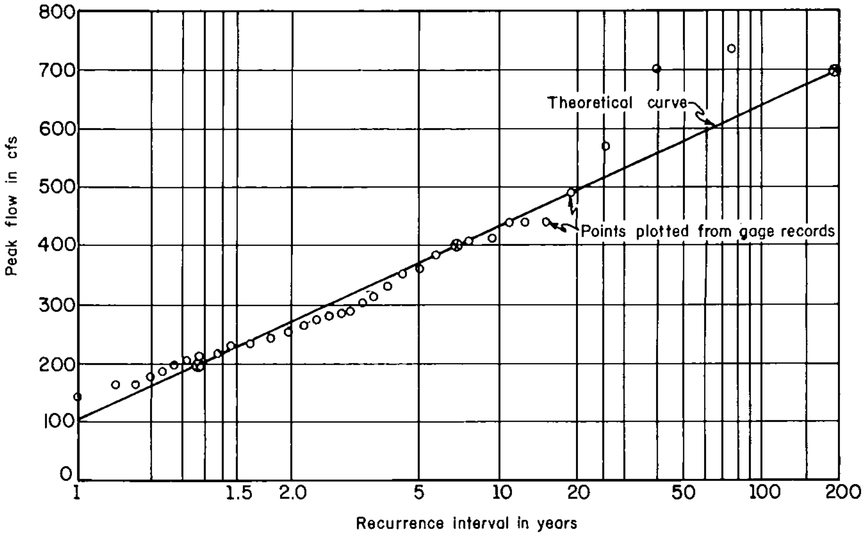
Local hydrologic conditions have a substantial influence on certain design aspects of surface water control. The relative amounts of average yearly precipitation and evaporation will determine the requirements for the most efficient handling of the estimated quantities of water. Where streamflow records are available, they are used to estimate the size of the spillway; where no records are available, flows into the tailings reservoir are based upon an estimate of precipitation runoff and snowmelt, taking into account the effect of local ground cover and soil conditions. These data and the volume of water in the tailings effluent and the water to be recycled are used to develop a water balance.

Rainfall and flood frequency curves can be developed from existing meteorological or streamflow data or by using methods contained in reference books on hydrology(11). A typical flood frequency curve is shown in Figure 6. The return period used in design will depend on the hazards downstream of the disposal area, the size and location of the deposit, and the type of tailings. Today, all large water supply dams are designed for the probable maximum flood.

## Flood Control

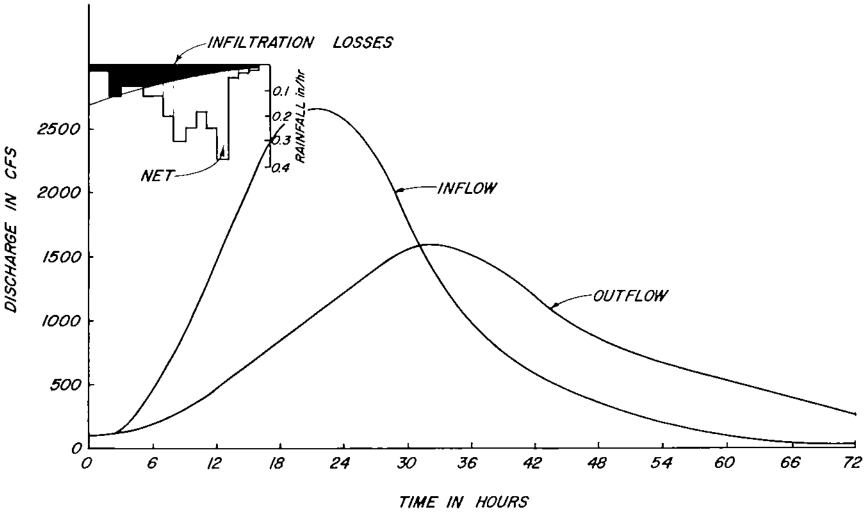
Precipitation runoff from high rainfalls or snowmelts has to be controlled to assure safe operation of the tailings disposal area. Several methods are available for the control of floodwaters:

1. Diversion of water around the tailings deposit,
2. Impoundment of all runoff waters in the reservoir, or,
3. Provisions of an engineered spillway so the flow can be routed through the tailings reservoir with no damage.



TYPICAL FREQUENCY CURVE OF ANNUAL FLOODS

Figure 6



TYPICAL INFLOW FLOOD AND
ROUTED OUTFLOW HYDROGRAPHS

Figure 7

In a wet climate area where large surface runoffs occur, a diversion system can be in the form of a conduit under the tailings, a diversion ditch around the deposit, or a spillway around the tailings retaining dam. For a side hill tailings deposit, where the watershed is generally small, storage of runoff can often be economically feasible. Direct precipitation on any tailings deposit will require engineering for either storage or design for controlled spilling. If the type of tailings will allow emergency spills of excess floodwater without contamination, a spillway can be designed as part of the tailings disposal structure. When a design flood is assigned, the flood can be routed through the tailings reservoir and spillway. The width of spillway can be varied for the routing so that the economics of height of dam vs. spillway width can be optimized. Spillway routing techniques are discussed in Design of Small Dams(12), and a typical inflow flood hydrograph and routed spillway outflow hydrograph are shown in Figure 7. Davies(13) describes the Buffalo Creek failure that resulted from inadequate provisions for controlling floodwater.

Figure 8

## Erosion

Because of the susceptibility of cohesionless materials to erosion, tailings deposits must be protected from flowing water. Heavy precipitation falling on embankment slopes will cause erosion if the slope is not protected. Also, water flow from discharge pipes, if not properly channelled, can cause surface erosion similar to that shown in Figure 8. Stream diversion channels must be protected against erosion and the potential for uncontrolled flow.

Slopes can be protected against erosion by placing a layer of well-graded gravel or by vegetating. Ludeke(14) and others (15) discuss the use of vegetative stabilization to minimize erosion. Aplin and Argall(16) list numerous references on stabilization of tailings dam slopes available in the technical literature.

## CASE STUDY

Terzaghi(17) in his paper "Effect of Minor Geologic Details on the Safety of Dams", discusses the importance of not overlooking the most unfavorable possibilities expected under the existing geologic conditions. Equal importance must be given to engineering details and combinations of both geologic and engineering conditions.

Basic features are rarely overlooked by the engineer during the design of a tailings dam; a spillway is provided for control of floods, slopes are flattened to ensure acceptable stability, increased freeboard provides an adequate margin of safety against overtopping, and drainage features are specified to eliminate the possibility of piping. Periodically, changing loading conditions, which can critically affect the behavior of an ancillary feature of a tailings disposal operation, result in design modifications. These can temporarily solve the existing problem, but they can also provide the ingredients for a much more serious problem. An example of a combination of existing conditions and disposal modifications that resulted in a retention dam incident is given below.

Figure 9 is a plan of a typical cross-valley deposit with coarse tailings retaining dams at both upstream and downstream ends of the deposit. The river was diverted through a tunnel in the right abutment. Both retaining dams were constructed of hydraulically placed coarse tails. As the height of the tailings dam was increased, a rockfill anchor dike was constructed at the toe of the downstream retaining dam.

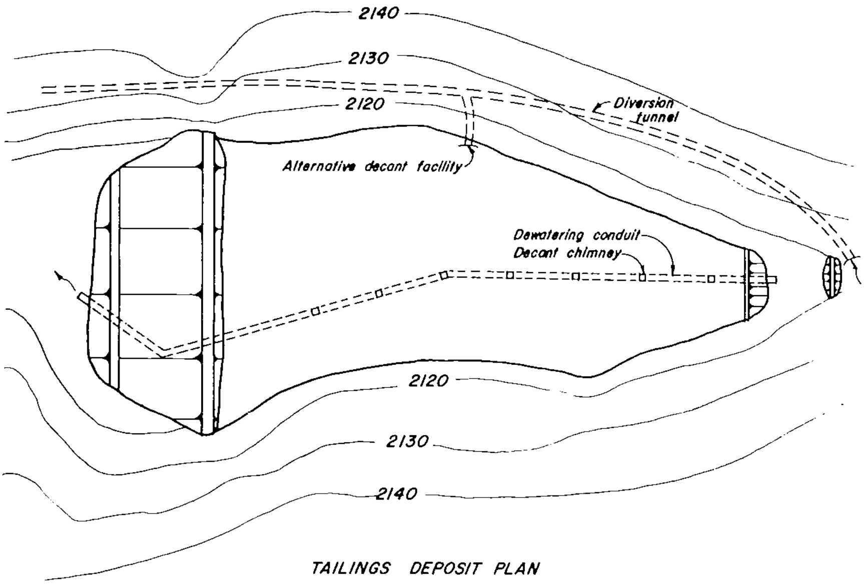
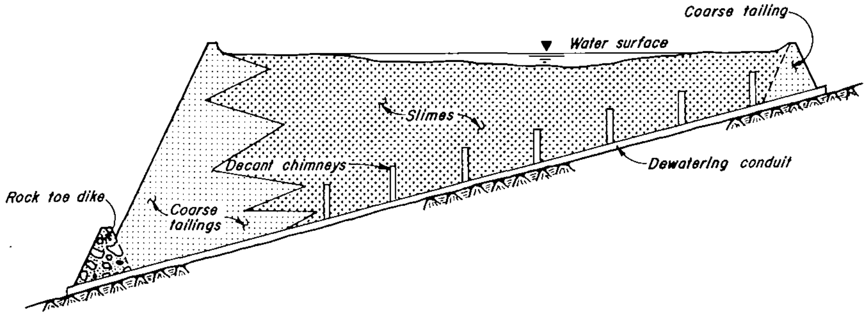


Figure 9

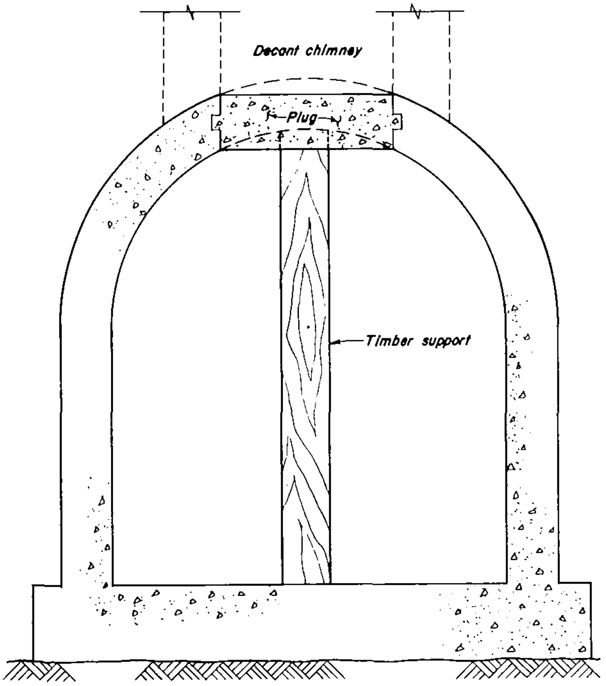
The original design included a reinforced concrete dewatering conduit placed in the valley bottom which was to be extended upstream as the tailings deposit was enlarged. Chimneys were used to control the location, size, and depth of the decant pond. New chimneys were added as the conduit was extended upstream. As the slimes inundated the lower chimneys and the decant pond moved upstream, the chimney openings were plugged at the top of the conduit. Figure 10 shows a developed profile through the deposit; a cross section of the reinforced concrete conduit is provided in Figure 11. Dewatering conduits are designed using the expected maximum loading from superimposed tailings. The estimated life of the mine and the size of the ore body provide the input data for determination of the final height of the tailings deposit.

Experience has shown that, for most tailings deposits around the world, the size of the ore body is usually underestimated. As more ore is found, the size and height of the tailings deposit are often increased and the margin of safety of the concrete conduit diminishes. Over a period of years, the integrity of the structure decreases as a re-



TAILINGS DEPOSIT PROFILE

Figure 10



DEWATERING CONDUIT

Figure 11

sult of the increased surcharge and wear and tear during prolonged operation. The monitoring program of the various features of the disposal operation will often show where maintenance of a structure is required. In this particular case, when structural deterioration of the conduit was noted, timber struts were installed as a temporary support until a more permanent side-valley dewatering scheme was realized. The reinforcement of the damaged structure was an acceptable temporary solution for the standard operating loading conditions.

As is invariably the case, however, loads do change with time. Porewater pressures in the tailings increased every year during the spring thaw (snowmelt). Excess hydrostatic pressures on the deteriorated concrete in the conduit caused a collapse of the structure. Flow of the semi-liquid tailings into the conduit resulted in the formation of a crater on the surface of the tailings deposit, Figure 12.

The collapse of a section of the dewatering conduit in a tailings deposit is probably a much more common incident than records show. Generally, pollution occurs downstream; this is cleaned up immediately, where possible, and other routine maintenance operations are initiated. In this particular case, the consequences were not so routine--the tailings and debris from the collapsed conduit dislodged the downstream timber struts. The "dog-leg" in the conduit in the vicinity of the downstream toe of the dam was the final ingredient needed for the formation of an Accident, Type 1 (discussed above).

Figure 12

The tailings, timber struts, and concrete debris formed an impervious plug in the conduit in the vicinity of the downstream toe of the dam as shown in Figure 13. With the seepage into the conduit, the hydrostatic pressure increased excessively and opened cracks in the concrete structure. The hydraulic gradient of the seepage water from the conduit was more than enough to move the coarse tailings--piping started to occur through some areas in the rockfill toe.

Figure 13

Immediate steps were taken to reduce the pressures in the conduit by removing the debris plug. In addition, the rockfill toe was enlarged with a filter zone placed between the existing and new rockfill.

Within a few weeks the condition of the deposit was back to normal. The modifications that had been made to the retaining dam increased the margin of safety to allow for extreme loading conditions. Shortly thereafter, the conduit was grouted, allowing seepage water to pass through a 10-inch pipe in the conduit.

This is an example of how several successive dam incidents could have produced a failure if remedial measures had not been undertaken. The excess hydrostatic pressure produced the conduit collapse; the collapse caused the flow of tailings into the conduit; the flow of tailings caused the plugging of the conduit; the plugged conduit caused water to build up behind the plug; the increased water pressure opened cracks in the conduit causing the water to flow through the coarse tailings; and the seepage water under excess hydraulic gradient started the piping. This "domino effect" shows that water is constantly influencing the performance of dams and can be relied upon to find weak links in any disposal operation.

## SUMMARY

Water plays a major role in the failure of tailings dams --it works either internally or externally. In situ water provides the ingredients for:

Increased neutral stresses, which reduce the shear strength. If, in the stability analyses, no allowance has been made for the higher neutral stresses (porewater pressures), the lower shear strength of the materials in the retaining dike will result in a decreased margin of safety and the possibility of slope failures.

Higher seepage forces, which set up the potential for piping. If the hydraulic gradient of the porewater in the tailings increases to the extent where particle movement occurs, a "pipe" (internal erosion) will form. Without remedial action (or a reduction in the loading conditions) the pipe will increase in size, causing collapse of the crest, overtopping, and washout failure as at Teton Dam [Chadwick, *et al.*,(18)].

Excess porewater pressures, which establish conditions that can result in liquefaction. Probably the least understood of the geotechnical phenomenon resulting in failure, liquefaction susceptibility can be reduced by increasing the density and keeping the porewater pressures to a minimum.

If the surface water in the watershed behind the tailings retaining dam is not controlled, damage or failure can occur:

Floods, resulting from heavy rainfall can overtop the crest of the dam and cause a washout; or where sidehill deposits encroach on floodplains, toe washout can occur followed by dike collapse.

Erosion, of fine cohesionless materials (tailings) occurs quickly; and, if remedial action is not taken, the crest can be breached, leading to total dam failure.

Each of the water loading conditions can result in failure without any contributing factors from other loading conditions. Combinations of extreme water loading conditions can have a cumulative effect that make it more difficult to determine the extent of calculated risk being taken. Increased safety factors, alternative control methods and emergency repair procedures must all be available to eliminate the role of water in the failure of tailings dams.

## REFERENCES

1. U.S. Committee on Large Dams (USCOLD), Lessons from Dam Incidents, USA, ASCE/USCOLD, New York, 1975.

2. Davies, Edmund, et al., Report of Tribunal Appointed to Inquire into Diasaster at Aberfan, H.L. (316) H.C. 553/1966-67, Her Majesty's Stationery Office, London, 1966.

3. Hazen, A., "Hydraulic Fill Dams", Transactions, American Society of Civil Engineers, Vol. 83, 1920, pp. 1713-1745.

4. Casagrande, A., "Role of the 'Calculated Risk' in Earthwork and Foundation Engineering", Journal of the Soil Mechanics and Foundation Division, ASCE, Vol. 91, SM4, 1965, p. 1-40.

5. Peck, R. B., "Advantages and Limitations of the Observation of Method in Applied Soil Mechanics", Geotechnique, Vol. 19, No. 2, 1969, p. 171-187.

6. Smith, E. S., Poindexter, D. R. and Bleikamp, R. H., "Observation of Approach to Tailings Dam Enlargement", Proceedings of the Conference on Geotechnical Practice for Disposal of Solid Waste Materials, ASCE, 1977, pp. 461-474.

7. Terzaghi, K., and Peck, R. B., Soil Mechanics in Engineering Practice, Second Edition, John Wiley and Sons, New York, 1967.

8. Lambe, T. W. and Whitman, R. V., Soil Mechancis, John Wiley and Sons, New York, 1969.

9. Cedergren, H. R., Seepage, Drainage and Flow Nets, John Wiley and Sons, Inc., New York, 1967.

10. Casagrande, A., "Seepage Through Dams", Journal of the New England Water Works Association, June, 1937.

11. Linsley, R. K., and Franzini, J. B., Water-resources Engineering, McGraw-Hill, New York, 1964.

12. U.S. Bureau of Reclamation, Design of Small Dams, 2nd Edition, Revised Preprint, United States Government Printing Office, Washington, D.C., 1974.

13. Davies, W. E., "Buffalo Creek Dam Disaster: Why It Happened", Civil Engineering, ASCE, July, 1973.

14. Ludeke, K. L., "Vegetative Stabilization of Copper Mine Tailings Disposal Berms of Pima Mining Company", Tailings Disposal Today, Proceeding of the First International Tailing Symposium, Miller Freeman Publications, San Francisco, 1973, pp. 377-410.

15. Argall, G. O., Editor, Tailing Disposal Today, Volume 2, Section 4, Papers on Reclamation, Vegetation and Abandonment, Miller Freeman Publications, San Francisco, 1979.

16. Aplin, C. L., and Argall, G. O., Editors, Tailing Dispoal Today, Proceedings of the First International Tailing Symposium, Miller Freeman Publications, San Francisco, 1973.

17. Terzaghi, K., "Effect of Minor Geologic Details on the Safety of Dams", Technical Publication 215, American Institute of Mining Engineers, 1929, p. 31-44.

18. Chadwick, W. L., et al., Independent Panel to Review Cause of Teton Dam Failure, Failure of Teton Dam, Report to U.S. Department of the Interior and State of Idaho, United States Government Printing Office, Washington, D.C., 1976.

19. Smith, E. S., "Tailings Disposal and Liquefaction", Transactions, American Institute of Mining, Metallurgical, and Petroleum Engineers, Vol. 244, 1969, pp. 179-187.