UNDER DRAINAGE AND FILTER DESIGN
INTRODUCTION

- The internal drainage is of crucial importance to the reliability and safety of a tailings dam throughout the dams’ whole life.
- Of all the factors affecting tailings dam stability, drainage is the one that can be implemented most easily, safely and economically throughout design, construction and operation.
- Careful and correct drain construction during the early stages of tailings dam construction constitutes cheap insurance against future expensive remedial works.
BASIC DEFINITIONS

- **DRAIN:**
  A DRAIN is a structure whose purpose is to remove excess water.

- **FILTER:**
  A FILTER is a structure whose purpose is to permit passage of fluid while preventing excessive movement of particles such that the soil being retained, or the filter itself, becomes unstable.
PURPOSE OF A DRAIN

- A drain consists of a flow conduit designed to remove slurry water from the tailings so that an outer wall of adequate strength to contain the tailings can be safely constructed.

- Principle of Effective Stress:
  
  Effective Stress = Total Stress − Pore Water Pressure
PURPOSE OF A DRAIN

- Fully drained situation – Effective stress, thus the strength of the tailings becomes a maximum because pore water pressure $= 0$

- Saturated situation – The higher the pore water pressure, the lower the effective stress and therefore the lower the strength of the material
PURPOSE OF A DRAIN

Two Main Purposes of a DRAIN:

1. To Remove excess interstitial water to prevent or control pore water pressure build-up

2. To Remove excess interstitial water as quickly as possible to speed up consolidation and promote rapid strength gain
PURPOSE OF A FILTER

- Two Main Purposes of a FILTER:
  1. Allow passage of water to the drainage conduit
  2. Prevent passage of particles into the drainage conduit
DRAINAGE IN VARIOUS TYPES OF TAILINGS DAMS

- Drainage in tailings dams depends to a significant extent on the method of construction

- Types of Impoundment Construction:
  - Upstream
  - Downstream
  - Centerline
  - Mixed Construction
DRAINAGE IN VARIOUS TYPES OF TAILINGS DAMS

- To be fully effective a drain should be located so that it substantially reduces the maximum head and dewater a defined zone of the tailings dam embankment

- Drainage requirements for the tailings dam are determined by seepage analyses
TYPICAL CROSS SECTION – UPSTREAM CONSTRUCTION
TYPES OF DRAINS

- TOE DRAIN:
  Near the outer toe of the tailings dam impoundment to promote consolidation of the outer wall of the impoundment and to prevent seepage through or over the starter wall due to build up seepage pressures against the upstream side of the starter wall.
TYPES OF DRAINS

- **MAIN DRAIN:**
  At a specified distance inside the tailings dam footprint to control pore water pressure build up and aid in consolidation for the life of the dam.

- **ELEVATED DRAIN:**
  At specified locations and elevations above foundation level to control pore pressure build up and ensure that the “phreatic” surface is kept a safe distance from the outer surface of the dam.
TYPES OF DRAINS

- BUTTRESS DRAINS:
  To control seepage which does find its way to the outer surface of the dam. These are usually used when the internal drains have failed or were not installed.
TYPICAL CROSS SECTION – TOE DRAIN
DESIGN PRINCIPLES

- The drain must be adequately sized to remove pore water from the tailings impoundment quickly enough to permit sufficient strength to be developed to create a safe impoundment.

- Material used in drains should normally be 200 to 1000 times more permeable than the drained soil/tailings.
A number of criteria have been developed by different researchers and organisations.

DESIGN PRINCIPLES

- **Definitions:**
  - $D_{15}$ – particle size where 15% of the particles of a soil are smaller than this size
  - $D_{85}$ – particle size where 85% of the particles of a soil are smaller than this size
DESIGN PRINCIPLES

- PIPING CRITERIA
  - The first basic requirement of the filter is to prevent soil migration
  
  - To achieve this purpose the voids in the coarser material must be small enough to prevent the finest particles in the soil or tailings to be retained from passing into the drain
DESIGN PRINCIPLES

- Theoretically the smallest particle that can fit through the gap between three touching spheres is about $1/6^{th}$ of the sphere diameter.

- First criteria proposed by Terzaghi for granular materials:

  $$D_{85} \text{ (filter material)} < 5$$
Granular material surrounding slotted or perforated pipe should meet the following criteria:

\[
D_{85} \text{ (filter) slot width} > 1.2
\]

\[
D_{85} \text{ (filter) hole diameter} > 1.0
\]
DESIGN PRINCIPLES

- PERMEABILITY CRITERIA

- The difference in permeability between any two adjacent materials should be sufficiently low so that excessive gradients do not occur.

\[ 4 < \frac{D_{15} \text{ (filter)}}{D_{15} \text{ (retained material)}} < 20 \]
DESIGN PRINCIPLES

FILTER REQUIREMENTS:
(a) C/B < 5
(b) D/C < 5
(c) Size of pipe opening < D

PERMEABILITY CRITERIA
(a) C/A between 4 and 20
(b) k filter = 100 * k retained
(c) D5 filter > 75 microns

BASIC FILTER CRITERIA
DESIGN PRINCIPLES

- Ensure that the hydraulic conductivity of the filter is not impaired by clogging

- Fines content of filters is limited:
  \[ D_5 \text{ (filter)} > 75 \text{ microns} \]

- Small amounts of clay can reduce the filter permeability substantially and therefore the fines content is limited to “non-plastic” fines
DESIGN PRINCIPLES

- INTERNAL STABILITY

- (Tan, Weimer et al, 1982)

\[
\frac{D_{85} \text{ (filter)}}{D_{15} \text{ (filter)}} < 5 \quad \text{Fines Fraction}
\]

\[
\frac{D_{50} \text{ (filter)}}{D_{35} \text{ (filter)}} < 5 \quad \text{Medium Fraction}
\]

\[
\frac{D_{85} \text{ (filter)}}{D_{50} \text{ (filter)}} < 5 \quad \text{Coarse Fraction}
\]
DESIGN PRINCIPLES

- (Sherard 1985)

\( Cu < 10 \) Internal instability is unlikely

Where \( Cu = \frac{D_{60} \text{ (filter)}}{D_{10} \text{ (filter)}} \)

\( 10 < Cu < 20 \) Internal instability is likely only with soils where the grading curve has sharp changes of direction

\( 20 < Cu < 75 \) Soil will generally be stable where the grading curve is smooth and has no sharp changes of direction or significantly flat lengths
DESIGN PRINCIPLES

- Typically the filter grading should be reasonably parallel to the grading curve of the material to be protected.

- Not always possible especially when the material to be protected has a very high fines content. In these case the properties of the material to be protected such as dispersivity, plasticity and grading characteristics must be carefully evaluated.
FILTER CRITERIA FOR FINE GRAINED SOILS

More extensive piping criteria, based on extensive testing, have been proposed by Sherard, Dunnigan and Talbot (1984) for application to fine grained soils.

<table>
<thead>
<tr>
<th>Soil Group Number</th>
<th>% of fines* smaller than 75 microns</th>
<th>Recommended Design Criteria (including safety factor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>85 to 100 %</td>
<td>$D_{15} \text{ (filter)} / D_{85} \text{ (retained material)} &lt; 9$</td>
</tr>
<tr>
<td>2</td>
<td>40 to 85 %</td>
<td>$D_{15} \text{ (filter)} &lt; 0.7 \text{ mm}$</td>
</tr>
<tr>
<td>3</td>
<td>Less than 15 %</td>
<td>$D_{15} \text{ (filter)} / D_{85} \text{ (retained material)} &lt; 4$</td>
</tr>
<tr>
<td>4</td>
<td>15 to 40%</td>
<td>$D_{15} \text{ (filter)} &lt; \text{ the pro-rata } D_{15} \text{ size between the size determined from the rules for soil groups 2 and 3.}$</td>
</tr>
</tbody>
</table>
DESIGN PRINCIPLES

TYPICAL GRADING ENVELOPE DESIGN

- Overflow
- Underflow
- Sand F
- Sand C
- Black Turf
- Residual Soil
- Dumprock
- 6mm C
- 19mm C
DESIGN PRINCIPLES

- Natural materials are variable, therefore it is prudent to gather as much information as is practically and economically possible.

- For this reason filter design always provides an “envelope” within which all material must fall.
CONSTRUCTION PRINCIPLES

- **GRADING**
  Filter materials are naturally variable – frequent grading checks are made to ensure that they are compatible

- **SEGREGATION**
  Where the filter material is widely graded, it is essential that construction methods prevent segregation of the material
CONSTRUCTION PRINCIPLES

- CLOGGING

Filter materials must be cohesionless and not contain excessive fine (<75 micron) material. The clayey material must either be avoided by borrowing only from clean sources, or must be removed by washing.

Non-plastic fines (silt) can be allowed to remain but again not exceeding the allowable 5%
CONSTRUCTION PRINCIPLES

- FILTER WIDTH

Filter materials are transported to site over long distances and are expensive. The tendency, therefore, is always to make the filters as narrow, or thin, as practically possible. Therefore much greater attention must be given to construction quality controls, as there is no margin for error.
CONSTRUCTION PRINCIPLES

- CONTAMINATION

Contamination can result in clogging of the filters. Filters transported to site are usually stockpiled prior to use. This necessarily results in wastage and in efforts to reduce wastage there is always great risk of contamination of the filter material by loading the underlying soil or clay with the filter material. Such contaminated filter material must be rejected and removed from the filter immediately.
OPERATING PRINCIPLES

- Where drains are completely covered during the construction phase there is usually little risk of damage during the operation phase.
- Drains which remain exposed, however, as is the case for most toe drains and main drains in tailings dams, risks of damage after construction and before covering with tailings can be high.
- It is essential in the operation phase that the dam operator is continually vigilant to ensure that where possible filters remain protected against contamination and that where contamination occurs the filters are carefully and meticulously cleaned before being covered with tailings.