TAILINGS POND DESIGN, MAINTENANCE AND INSPECTIONS

2020 IAAP Convention
Springfield, Illinois

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PRESENTATION OBJECTIVES

SURFACE TAILING IMPOUNDMENTS

- Overview of Engineering Design
- Project Design Approach
- Construction Oversight
- Inspection and Maintenance
Why is Engineering Design Important?

- **Comply** with Federal, State and Local Regulations and Permit Requirements

- **Reduce Risk** - Major Failures have led to an Industry-Wide Review of Design and Management Practices
WHY ARE SOME ENGINEERING DESIGN CONSIDERATIONS?

- Geotechnical and Geologic Conditions
- Hazard Classification
- Impact on Future Reserves
- Surface/Subsurface Water Management (H&H)
- Distance and Elevation from Processing Plant

- Ease of Access
- Borrow Material Type, Location and Availability
- Dust Control
- Environmental Constraints
- And many other...
TYPES OF IMPOUNDMENTS

INCISED IMPOUNDMENT

PARTIALLY INCISED IMPOUNDMENT

EMBANKMENT FILL IMPOUNDMENT
GENERAL DESIGN TYPES

MAIN DESIGN APPROACHES

- Embankment
- Upstream
- Centerline
- Downstream

Reference: Vick S.G., 1990
GENERAL DESIGN TYPES:

EMBANKMENT

- Constructed to full height prior to deposition
- Good permanent tailings and water storage
- Good seismic resistance
- Requires compacted natural borrow materials
- Relatively high cost
GENERAL DESIGN TYPES:
UPSTREAM

- Constructed progressively using tailings
- Most common worldwide
- Lowest cost compared to other methods

- Not suitable for significant water storage
- Poor seismic resistance
- Raising rate restrictions of 15-30 feet per year may apply
GENERAL DESIGN TYPE: CENTERLINE

- Constructed progressively using tailings or natural borrow materials
- Good temporary water storage ability
- Moderate cost
- Acceptable seismic resistance
- Raising rate restrictions may apply
GENERAL DESIGN TYPES:

DOWNSTREAM

- Constructed progressively using tailings or natural borrow materials
- Good permanent water storage suitability
- Good seismic resistance
- Relatively high cost (compared to centerline and upstream construction methods)
DO SURFACE TAILINGS IMPoundMENTS HAVE A HIGHER RISK OF FAILURE?

Failure rate over the past 100 years is estimated to be 1.5%\(^1\)

More than 100 times higher than conventional water storage dams at 0.01%\(^2\)
WHY ARE TAILINGS IMPOUNDMENTS DIFFERENT FROM OTHER DAMS?

- Often raised repeatedly over their lifecycles
- Stores a mixture of minerals and water
- When full, they generally remain in place (risk remains for many years)
WHAT ARE THE MOST COMMON CAUSES OF IMPOUNDMENTS FAILURES?

01 OVERTOPPING

02 PIPING THRU EMBANKMENT

03 PIPING THRU FOUNDATION
OTHER COMMON CAUSES OF IMPOUNDMENTS FAILURES

- Embankment slope stability
- Earthquakes, ground motions and faults
- Foundation degradation
  - Karst development
  - Liquefaction
  - Loss of fines over time
- Equipment malfunction or failure
WHAT DO COMMON FAILURE CAUSES LOOK LIKE?

- Uncontrolled flow of water over, around and adjacent
- Erosive wave action

OVERTOPPING (most common)
WHAT DO COMMON FAILURE CAUSES LOOK LIKE?

PIPING THROUGH EMBANKMENT
GEOTECHNICAL ISSUES WITH EMBANKMENTS

UPSTREAM CONSTRUCTION METHOD

- Low shear strength tailings – soft, loose
- No internal drainage, high water pressures
- Poor compaction of fill materials
- Steep side slopes
- Weak foundation
- Liquefiable soils under seismic loads
GEOTECHNICAL ISSUES WITH EMBANKMENTS

Feijão Dam Failure January 24th, 2019
Brazil Vale S.A.’s Córrego do Feijão Iron Ore Mine
GEOTEchnical Issues

Feijao Dam Baseline Conditions

- The constructed using the *upstream construction method* over a period of 37 years in 10 raises.
- Height was *80m with crest length of 700m*.
- No new raisings were constructed after 2013, and tailings disposal ceased in July 2016.

FEIJAO DAM FAILURE

Figure 18: Failure of Dam I


- Observed Initiation (OI) at the Center of the Crest;
- 0.2 s After OI, Initial Bulging of the Face;
- 1.4 s After OI, Showing Escalation;
- 2.4 s After OI, Widening Collapse of the Crest and Increased Bulging of the Face;
- 2.6 s and 3.6 s After OI when the Crest and Bulging Join in Failure
The dam was extensively monitored with:

- Survey monuments,
- Inclinometers,
- Ground-based radar to monitor surface deformations of the face of the dam, and
- Piezometers to measure changes in internal water levels, among other instruments.

No significant deformations or changes prior to failure.

PRIMARY FACTORS AFFECTING FAILURES

- Absence of design by a knowledgeable professional, and/or
- Lack of understanding of geotechnical and dam engineering principals, and
- Not following O&M procedures and schedules
### DESIGN APPROACH OVERVIEW

**DAM SIZE and HAZARD CLASSIFICATION (varies by state)**

<table>
<thead>
<tr>
<th>HAZARD CLASSIFICATION</th>
<th>HAZARD POTENTIAL</th>
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</thead>
<tbody>
<tr>
<td>HIGH</td>
<td>Probable loss of life</td>
</tr>
<tr>
<td></td>
<td>Major economic losses</td>
</tr>
<tr>
<td>SIGNIFICANT</td>
<td>Possible loss of life</td>
</tr>
<tr>
<td></td>
<td>Major economic losses</td>
</tr>
<tr>
<td>LOW</td>
<td>Loss of life not expected</td>
</tr>
<tr>
<td></td>
<td>Minimal property damage</td>
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</tbody>
</table>
DESIGN OVERVIEW

The following tasks are for a site located in the Midwest:

- Site Reconnaissance and Meeting with the Owner
- Development of Preliminary Layout
- Exploratory Drilling and Sampling
- Laboratory Soil and Rock Testing

Analysis
- Applicable Regulations and Permit Requirements
- Hazard Class
- Hydraulic and Hydrologic Modeling
- Regional Flood Flows
- Design Flood Flows (PMP)
- Routing of Design Flood
- Slope Stability and Seepage Analysis (Slope/W and SEEP/W)
DESIGN OVERVIEW

The following tasks are for a site located in the Midwest:

Design Report with Recommendations for Construction
  • Site Preparation
  • Fill Source (Embankment, Riprap, Toe Drain)
  • Toe Drain Design
  • Placement and Compaction of Fill

Final Design Drawings and Specifications

Bid Documents and Bid Evaluation

Construction Oversight and Monitoring
EXISTING TOE DRAIN MITIGATION
TOE DRAIN GROUTING

LEGEND
- Grouting Locations
- Confirmation Borings
- Elevation Contours (1 Foot Interval)

NOTES:
1. BASE MAP SOURCE PROVIDED BY CLIENT
2. LOCATION OF EXISTING AND PROPOSED FEATURES WERE DETERMINED BY FIELD MEASUREMENTS AND DATA PROVIDED BY CLIENT

APPROXIMATE GROUTING LOCATIONS

GROUT VOLUME (cuf)

GB-01 120
GB-02 48
GB-03 45
GB-04 45
GB-05 32
GB-06 27
GB-08 62
GB-07 22
GB-09 14
GB-10 40
GB-11 97
GB-12 58
GB-13 65
GB-14 122
GB-15 38
GB-16 38
GB-17 81
GB-18 38
GB-19 38
GB-20 81
GB-21 22
GB-22 14
GB-23 12
GB-24 18
GB-25 34
GB-26 30
GB-27 13
GB-28 30
GB-29 15
GB-30 30
GB-31 22
GB-32 14
GB-33 42
GB-34 28
GB-35 18
GB-36 12
GB-37 10
GB-38 8
GB-39 4
GB-40 2
GB-41 1
GB-42 0
EXISTING EMBANKMENT NOTCH DETAIL

Not to scale
CONSTRUCTION OVERSIGHT & MONITORING
CONSTRUCTION DOCUMENTATION
RESPONSIBILITIES

THE OWNER

Inspection, operation and maintenance and consequences of failure

REGULATORY AGENCIES

Developing design standards
Issuing permits
Enforcing regulations
WHAT SHOULD I BE DOING?
Or the Never-Ending Duties of an Embankment Owner

Perform informal and formal inspections (i.e. daily, weekly, monthly)

Special cases: prior to, during, and after major weather events including rain, snowmelt, and/or wind

Develop an O&M Plan

Develop an EAP (if necessary or prudent to do so)
• What should we look for?
• Where do I start?
EMBANKMENT INSPECTION LEVEL OF EFFORT

INITIAL INSPECTION

• Review Existing Information
• Visual inspection
• Some engineering evaluation, i.e. stability, spillway capacity?
• Evaluate findings & recommendations
DAM INSPECTION CHECKLIST

- Look for changes
- Document conditions (notes and photos)
- Use a standardized checklist
EMBANKMENT INSPECTION – WHAT TO LOOK FOR

- **TOE SEEPAGE**
- **CRACKING**
- **SLOPE FAILURE**
- **OVERTOPPING**
EMBANKMENT INSPECTION – WHAT TO LOOK FOR

- Trees
- Leakage
- Sink holes
- Structural movement
EMBANKMENT INSPECTION – WHAT TO LOOK FOR

ANIMAL BURROWS
TYPICAL EMBANKMENT O&M

- Vegetation maintenance
- Animal control
- Exercise of gates, values and pumps
- Clearing of sediment and debris
- Instrumentation monitoring/data collection
- Water level monitoring
- Vandalism, dam access, and security
O&M PLAN CONTENTS

1. Background information and impoundment description (as built drawings, specifications)
2. Key personnel and contact information
3. Operating instructions (e.g., gates, valves, pumps)
4. Inspection and maintenance guidelines and schedule
5. Emergency operations guidelines (along with or in lieu of EAP)
EMBANKMENT CARETAKER

One primary person is designated to maintain information and act as embankment caretaker/liaison

Keep a binder with:

- Construction information, photos and plans
- Maintenance records
- O&M Plan
- EAP
- Inspection Checklist
- Other Relevant Documents
• To verify if a dam is performing as intended, and to identify changing conditions, the following should be performed:

- Visual observation
- Movement indicators (e.g. Inclinometers, crack gauges)
- Pressure indicators (e.g. piezometers)
- Water level and flow (e.g. staff gauge, discharge point, rain gauges)
- Weather forecasts and warnings
Thank You!
Questions?

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