Predictive Models & Available Software

Presented by
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• Antecedents
• Newtonian / non-Newtonian flows
• Available models that allow the simulation of non-Newtonian flows (tailings)
• Other models used in practice
In the mining industry specific guidelines and/or procedures to perform dam breach analysis for tailing storage facilities (TSFs) and the resulting “flooding conditions” are not available as they do for water dams.

Generally Dam breach analysis and flood-wave routing is needed to assess the effect of a potential dam failure downstream of a TSF, which in turn will guide on the appropriate Emergency Action Plan (EAP) for the TSF under a potential dam breach.
Most numerical models for dam-break analysis have been developed for water-storage dams. The intention of these models is to predict the flood characteristics depending on dam type and break mechanisms and breach size.

Significant work is still needed for dam-break analysis of tailings dams. Models need to account for Hyper-Concentrated Flows (non-Newtonian).

Issues:
- No specific software for modeling dam breaks that contain tailings
- Modeling dam break parameters predictions
- Modeling flood propagation and downstream flow predictions
- Type of failure: Sunny Day /Rainy Day
## Newtonian vs. Non-Newtonian Fluids

<table>
<thead>
<tr>
<th>Newtonian</th>
<th>Non-Newtonian</th>
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<tbody>
<tr>
<td>- Has a constant viscosity with rate of deformation&lt;br&gt; - It is not time dependent&lt;br&gt; - Simple&lt;br&gt; - Water</td>
<td>- The absolute viscosity changes with rate of deformation&lt;br&gt; - Depends on time and thus flow rate&lt;br&gt; - More complicated&lt;br&gt; - Paints, sludges, tailing&lt;br&gt; - There is no simple relationship between the stress and the rate of strain</td>
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**Fluid Mechanics – Finnemore and Franzini**
• Fluids resist flow. This phenomenon is known as viscosity.
• Fluids like water and gasoline behave according to Newton's model, and are called Newtonian fluids. Other fluids such as ketchup, blood, yogurt, mud, and cornstarch paste DON'T follow the model.
• For some fluids (like mud or snow) you can push and get no flow at all until you push hard enough, and the substance begins to flow like a normal liquid. This is what causes mudslides and avalanches.
What Model Should I Use?

HEC-RAS  MIKE
SMPDBK  FLO-2D
DAMBRK  DAN-3D
HEC-HMS  FLOWAV
DAN-W

What will I be modeling?
And what is the main goal?
Predictive Models & Available Software

National Weather Service

SMPDBK → DAMBRK → BOSS DAMBRK → FLDWAV → J. O’Brien FLO-2D
SMPDBK → BOSS

Non-Newtonian Models
(Water and sediment)

Scott McDougall

DAN-W → DAN-3D

Some common models

Newtonian Models
(Water)

HEC-RAS
HEC-HMS
MIKE
Selecting a Model

• What will the model be used for?
  – Emergency Action Plan
  – Environmental Impact Study
  – Hazard Classification

• How detailed should the results be?

• What information is known?

• Different models may predict different portions of a dam break (hydrograph and routing) more accurately.

• Model Output: APPROXIMATION = > CAUTION
Models for Non-Newtonian Flows

- These models allow direct modeling of tailings:
  - DAMBRK
  - FLO-2D
  - FLDWAV
  - DAN-3D

Waihi Tailing Dam, New Zealand
Non-Newtonian Models - DAMBRK

- Developed by the National Weather Service in 1984
- Updated by BOSS International
- Predicts the dam breach wave formation and its downstream progression
- Three main features:
  - Ability to describe dam failure mode temporally and geometrically
  - Computation of the outflow hydrograph through the breach
  - Ability to route the outflow through a downstream channel
Non-Newtonian Models - DAMBRK

- Good for determining potential influenced area.
- Allows the user to input geometric and temporal data for the dam break to accurately predict the initial breach wave, including modeling piping and overtopping failures.
- Has the ability to route the flow from the breach hydrograph.
- The data entry is very flexible and will run the model on limited data, but the more data, the more accurate results obtained.
Non-Newtontian Models - DAMBRK

- Ability to model non-Newtonian flows by allowing the user to assign fluid unit weights, dynamic viscosity, initial shear strength, and stress rate of strain.
- Has the ability to route supercritical, subcritical, or mixed flows for non-Newtonian fluids.
- Case studies have returned sound results for outflow volumes, peak discharges, and peak flood elevations.
Non-Newtonian Models – BOSS DAMBRK

• Developed from original NWS DAMBRK code
• Improvements include:
  – Faster calculations
  – Graphic interface
Non-Newtonian Models – FLO-2D

- FLO-2D model grew out of a model developed by Jim O’Brien for FEMA called MUDFLOW in 1989.
- Predicts flood hazard, mudflows, and debris flows over alluvial fans.
- Good for predicting flow path and area.

- Uses a grid system to determine the layout of the floodplain based on elevation, roughness factor, and flow reduction factors.
- Both clear and sediment flow can be modeled using a rheological model.
• The discharge is predicted by estimating the depth of flow over each sector and summing up all the sectors on each of the four sides of the grid.
• Allows sediment continuity and has the ability to model remobilization based on changes in the landscape and fluid properties.
• Accuracy is dependent on the density of the grid system and the data available.
Non-Newtonian Models – FLDWAV

- Developed by the NWS to replace DAMBRK.
- Adds wave front tracking for more accuracy and better time based models.
- Allow dam breach prediction and calculating potential concerned area.
- Designed to model rapid flood events from large precipitation events or dam break occurrences.

Merrespruit Dam, South Africa 1994
Non-Newtonian Models – FLDWAV

- Predicts flow through a single stream or network of streams using real time forecasting technology.
- Takes into account terrain and material properties at different time intervals and adjusts flow pattern.
- Based on the 1-D solution to the Saint-Venant equations for unsteady flow.
- Secondary functions allow the model to predict flow through hydrologic structures and river basins.
- Includes special models for dam break analysis, time based flood predictions, pumping situations, and other rapid flow scenarios.
Non-Newtonian Models – FLDWAV

• Allows the flow to change from subcritical to supercritical and back based on location and time interval.

• Can be used to model one dimensional unsteady debris flow (or tailings).

• Caution recommended when use the model to predict flow under bridges, through storm sewers, and through culverts unless it is properly imported as a rating curve.
• Based on a theory of runout analysis developed by Hungr (1995).
• Based on shallow flow assumptions and is best suited to shallow mass movements, where the flow thickness is at least an order of magnitude less than the length of the moving mass and the movement vectors are approximately parallel with the bed.

• A profile of the travel path (including entrainment zones) and the source area, and the width of the path is needed.
• The solution may be unstable in certain cases where the flow is deep, or where abrupt changes of slope occur.
• Developed by Scott McDougall as a PhD thesis in 2006.
• Runs on the same basic principles as DAN-W but adds the ability to model flow over 3D surfaces.
• Designed to model landslides at high velocity from non-Newtonian fluids and solids.
• Purpose is to predict the impacted area from the slide.
• Four Key Features
  – Simulate flow over complex 3D terrain
  – Prediction of internal stresses and strains
  – Ability to account for entrainment of material in the flow path
  – Predict alterations in flow path and properties depending on terrain
• A digital terrain model (topography) of the area is needed.
Non-Newtonian Models – DAN3D

- Based on the two-dimensional Lagrangian solution of unsteady flow over three dimensions.
- Uses flow velocity and depth calculated from the model to predict the impacted area.
- It does not model abrupt changes in terrain or flow type because it smooths out the results.
Other Models (Newtonian Flows)

- **CCHE2D-DAMBREAK**
  - two-dimensional shallow water equations
  - The University of Mississippi, 2005

- **SMPDBK**
  - NWS

- **HEC-RAS**
  - USACE

- **MIKE**
Other Models – SMPDBK

• Developed by the NWS as a simpler version of DAMBRK
• Good at obtaining dam classification and potential dam break risk
• Returns virtually the same results as the normal DAMBRK software in simpler cases
• Quick and easy to use and does not require as many inputs as DAMBRK
• Three assumptions to simplify the model:
  – Rectangular and constant initial breach
  – Constant reservoir surface
  – Peak flow time equal to the breach development time
• Limitations can be helped by providing an equivalent breach width value and dam break time.
Other Models – HEC-RAS

- HEC-RAS was developed by the U.S. Army Corps of Engineers
- A routing method for modeling how water moves downstream
- Does not model non-Newtonian fluids
- Good at predicting downstream flooding effects from an upstream event, such as a dam break
Simulate the resulting flood wave front and downstream consequences of an upstream event.

Models downstream effects by reading the results of dam break analysis.

Three options to get initial dam break flood wave:

- Compare dam failure to past failures of similar magnitude
- Predict hydrograph equations from past dam failures
- Use the model
Other Models – MIKE 21

• Two-dimensional software based on the original MIKE 11 model
• Focuses on flow of Newtonian fluids over initially dry terrain
• Good for analysis to estimate potential effected areas

Los Frailes, Spain
Other Models – MIKE 21

• Predict a wide range of floodplain situations in two dimensions
• Allows sub-critical, super-critical and mixed flows to be modeled
• Based on solutions to depth average equations that describe the conservation of mass and momentum.
• Caution should be used when modeling steeply rising floods and shallow wave fronts
Case Study -
Downstream Routing
Comparison with Historic Dam Failures (Rico et al., 2007)
Resistance to Flow for Sediment Hyperconcentrations (Julien et al., 2010)

\[ V/u^* = 0.4 \ (h/d50) \]  
*Dispersive*

\[ V/u^* = 5 \ (h/d50)^{1/6} \]  
*Manning*

\[ V/u^* = 5.75 \ \log \ (h/d50) \]  
*Turbulent*
Conclusions

• It is a complex process. Even for water dams only a few decades of research has been done
  – Water (Dam breach process, dam breach parameters significant uncertainty)
  – Tailings (Non Newtonian, Two Phase Flow, properties may change with time, dam breach process and routing)

• The objective of the model could be:
  – Hazard Classification
  – EAP
  – Influence Area for Environmental Studies
Conclusions

• With different models available it is important to define the goal of the analysis
  – Newtonian vs Non-Newtonian

• Model outputs provide approximations. There is always uncertainty

• Water, sediment and chemistry are key components of the dam breach tailings flow characteristics

• The routing from a tailings dam breach moving downhill is determined by the volume of flow, the characteristics of the breach in the dam and the slope of the hillside

• Chemical properties not included in Non-Newtonian models which add uncertainty to the results obtained
1. Several models are using in practice. But at present we are lacking of a robust flow model.

2. Available empirical correlations such as those of Rico et al. (2007) for tailing dam breaks can be applied to provide a first estimate on the volume of tailings spills, tailings run-out distance. Furthermore, the worst case scenario estimation based on the envelope curves developed from historic dam failures from tailings dams can be very useful.

3. It is key to look at historic dam failures to “calibrate” our assumptions and results.
Thank You!
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