

# Tailings Dam Classification and Breach Analyses, Perspectives from the Canadian Dam Association



May 10, 2017

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Closure Conference  
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# Outline of Presentation

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- **Why do we Classify Dams and what is the purpose.**
- **How is classification related to breach analyses.**
- **How do tailings dams differ from water dams and how does that effect classification.**
- **What methods can be used to perform breach analyses.**
- **How Amec Foster Wheeler Canada approaches dam classification and breach analyses that we have used for dams in other localities.**

# Dam Classification

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Why do we classify dams and what is the purpose?

**Dam Classification** as defined by the Association of Dam Safety Officials (ASDSO) for all dams:

“The hazard potential classification for a dam is intended to rank dams in terms of potential losses to downstream interests if the dam should fail for any reason. The classification is based on the incremental adverse consequences (after vs. before) of failure or mis-operation of the dam, and has no relationship to the current structural integrity, operational status, flood routing capability, or safety condition of the dam or its appurtenances. The hazard potential classification is based on potential adverse impacts/losses in four categories: environmental, life line, economic, and/or human life.”

**It is important to understand that the classification is based on the potential consequences of failure and is not related to the credibility of the failure mode.**

## Slide 4

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**SA44**

Still missing a slide that shows the purpose of the presentation and the outline to help the listener know what is coming

Small, Andy, 4/25/2017

- **The Canadian Dam Association (CDA) and other associations have adopted, modified, or used a similar dam classification definition.**
- **CDA was one of the first organizations to apply this definition to the classification of “mining dams”, which includes tailings dams, in their 2013 Technical Bulletin:  
“Application of Dam Safety Guidelines to Mining Dams”.**

**This document can be purchased through their website.**

# Dam Classification CDA (2013)

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CONSEQUENCE CATEGORY	POP'N AT RISK	INCREMENTAL LOSSES		
		LOSS OF LIFE	ENVIRONMENTAL & CULTURAL VALUES	INFRASTR. & ECONOMICS
EXTREME	Permanent	More than 100	Major loss... Restoration impossible...	Extreme losses...
VERY HIGH	Permanent	100 or fewer	Significant loss... Restoration impractical...	Very high economic losses...
HIGH	Permanent	10 or fewer	Significant loss... Restoration probable...	High economic losses...
SIGNIFICANT	Temporary Only	Unspecified	No significant loss...	Loss to recreational facilities...
LOW	None	0	No long term loss...	Low economic loss...

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## Items Controlling Classification

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- Not related to the credibility of the failure mode
- Highly dependent on the number of people affected
- Environmental and Cultural Values
- Economic losses (third parties)

**Without Having Some Understanding of the Results of  
a Failure, a Dam Cannot be Classified**

Dam Breach Analyses helps understand what can happen.

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## Slide 7

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**SA45**

When speaking to this, maybe comment that many US classifications do not consider the environmental consequences that are a big driver for mining dams

Small, Andy, 4/25/2017

## Amec FW Recommended process for classification

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- Assume failure can occur without consideration of the probability of failure.
  - Consider flood induced and fairweather types of failures such as seepage, earthquakes, and landslides.
  - Develop a preliminary dam classification based on conservative assumptions of the consequences of failure and empirical relationships.
  - Conduct dam breach analysis to support the classification.
  - Consider post failure effects (acid generating tailings and water quality).
  - Establish criteria based on the classification and other considerations of owner and regulator.
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## Is it Water, is it Tailings, or is it Tailings that act like water?

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- Tailings dam failures are different from water dam failures in that in addition to a release of water there is potential for the dam breach to also result in the release of liquefied tailings.
  - Water flows much differently than tailings based on their non-Newtonian properties and a breach does not mean that all of the tailings will leave the impoundment.
  - If the tailings will liquefy and how far they may travel depends on the physical properties of the tailings and dam breach analyses should account for these differences.
  - If, following closure, the dam does not store water and tailings are non-liquefiable then the facility can be re-classified as a non-dam landform type of facility.
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# Summary of Dam Breach Models



Models	Type	Dam Breach (Water)	Newtonian Flow Routing	Non-Newtonian flow Routing	User Interface	Computing Cost
FLDWAV	1-D	Yes	Yes	Yes	Text/Graphic	Medium
DAMBRK	1-D	Yes	Yes	No	Text	Medium
BREACH	1-D	Yes	No	No	Text	Low
HEC-RAS	1-D/2-D	Yes	Yes	No	Graphic	Medium
FLO-2D and 3D	1-D/2-D/3-D	Yes	Yes	Yes	Graphic	Medium
MIKE 11 & MIKE21	1-D/2-D	Yes	yes	No	Graphic	High
Telemac-MASCARET System	2-D	Yes	Yes	No	Graphic	Medium to High
DAN3D	2-D	-	-	-	Graphic	not commercially available
MADFLOW	2-D	-	-	-	Graphic	not commercially available

# WISE URANIUM PROJECT

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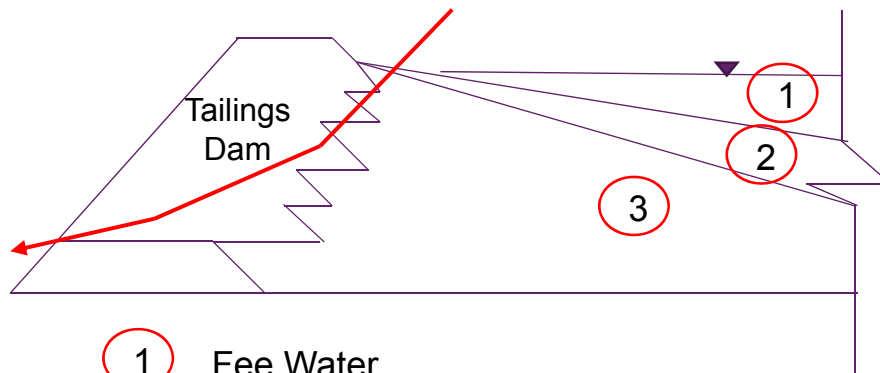
## World Information Service on Energy Uranium Project

- Website – [www.wise-uranium.org](http://www.wise-uranium.org)
- Chronology of major tailings dam failures since 1961. Lists 106 incidents and presents Location, Parent Company, Ore Type, Type of Incident, Release description, and Impacts.
- Tailings Flow Slide Calculator; with inputs of:  
Height of Dam, Bed Slope, Unit Weight, Bingham Yield Strength, and, Bingham Plastic Viscosity.

The calculator uses a Bingham plastic model to represent the flow behavior of the liquefied tailings material: motion of the fluid only commences when a threshold shear stress is exceeded.

To calculate run-out distance

# Tailings Dam Breach Analyses – State of Practice



- 1 Free Water
- 2 Fluid
- 3 Tailings Liquefiable/  
Non Liquefiable  
Material

Zone	Current Practice
1	Can be analyzed using water based model (eg. HEC-RAS)
2	Can be modelled as semi-solid (sediment?) material (eg. Flo-2D)
3	If non-liquefiable –no flow; If liquefiable – will flow – can be modelled as debris flow (eg. DAN3D)
No tools available that can model all three phases simultaneously	

# EXAMPLE 1 – Mount Polley – August 4, 2014

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## EXAMPLE 2 – Samarco – November 5, 2015





# Methods of Breach Analyses

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- There are good computer models for estimating runout for water, fluid tailings and non-liquefiable tailings but a completely coupled analyses has yet to be developed due to the complexity of the flow.
  - The level of modeling required should be based on the dam containing the facility with the potential highest classification.
  - An empirical method has been developed based on historical dam failure information by Rico et. Al. (2008). The Rico data base has since been extended by CDA.
  - The empirical database provides an indication of runout distance and volume, making it possible to perform an initial classification of the dam.
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# Empirical Database (Rico et al. 2008)

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Rico - proposed a set of simple empirical equations that relate the flow of tailings to some geometric parameters of the impoundment or the total volume of the flow.

Parameter considered	Correlated flow characteristic
Dam height (H)	Run-out distance ( $D_{max}$ )
Outflow volume (tailings) ( $V_F$ )	Run-out distance
Dam factor ( $H \times V_F$ )	Run-out distance
Impoundment volume (tailings) ( $V_T$ )	Outflow volume
Dam height (H)	Peak discharge ( $Q_{max}$ )
Dam factor	Peak discharge

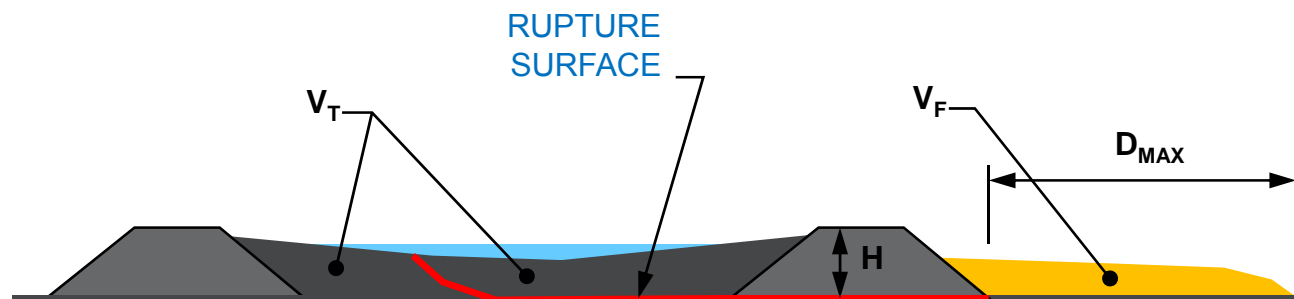
**Primary data sources:**

**UNEP (1996)  
USEPA (1997)  
ICOLD (2001)**

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## Rico et al. (2008): Definitions

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$V_T$  “Volume of tailings stored at the dam<sup>\*</sup>”

$V_F$  “mine waste outflow volume<sup>\*</sup>”

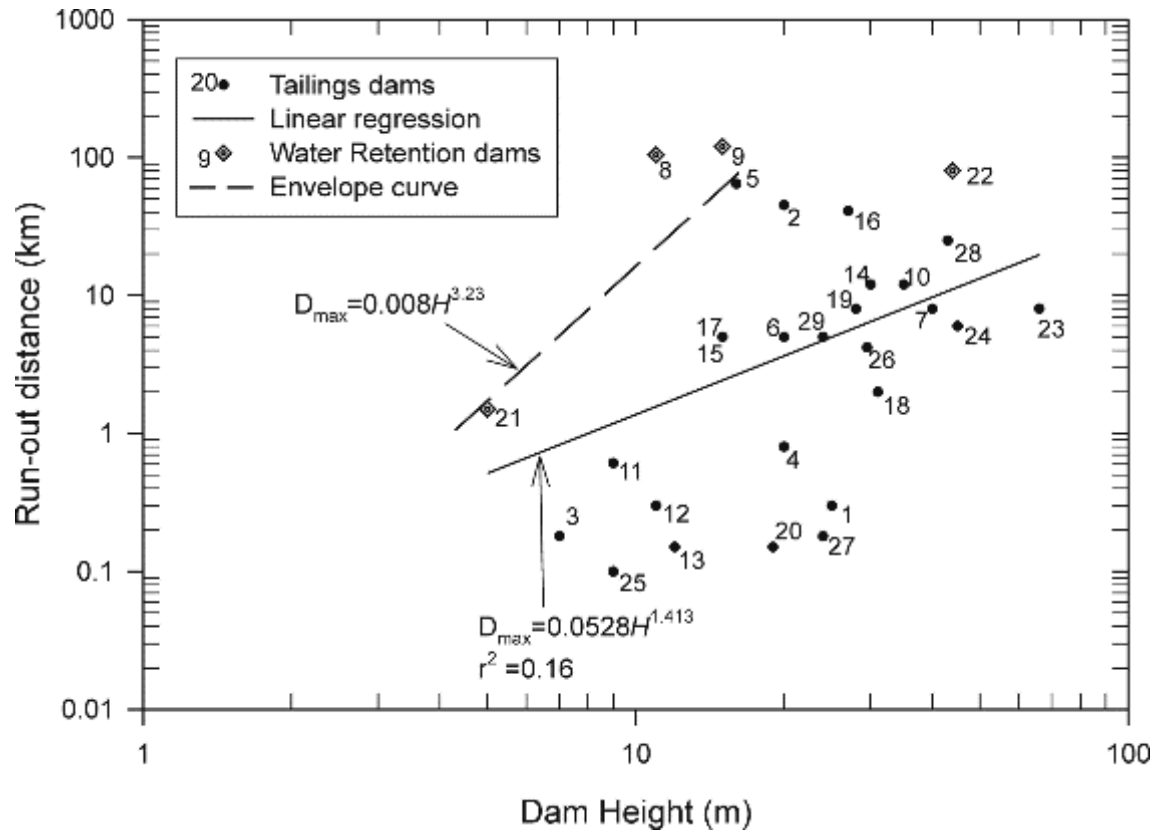
$D_{MAX}$  Runout distance of tailings

$H$  Dam height

**\*Terminology not clear. Water volume might be included.**

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# Run-out distance vs dam height

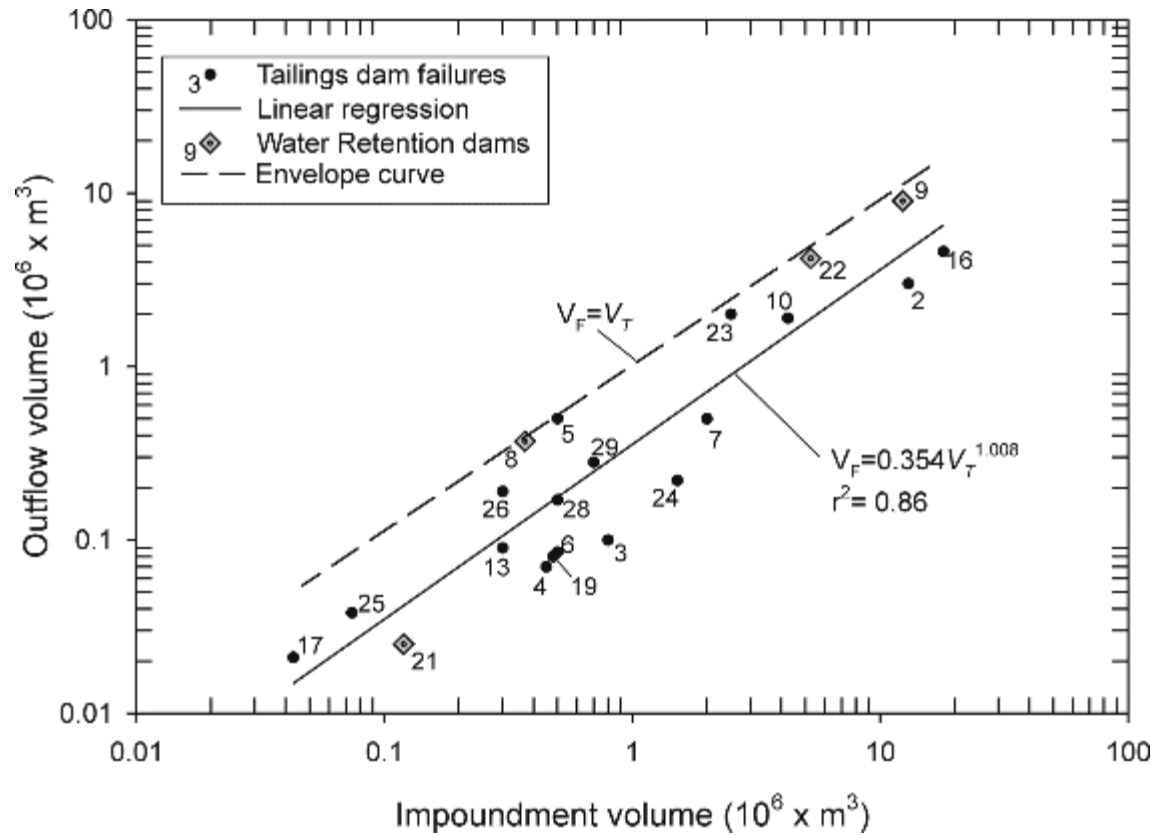


SL5

modified equations..from L to Dmax

Shielan Liu, 9/28/2015

# Outflow Volume vs Impoundment Volume



# Updated database with Additional parameters by CDA

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## Factors influencing tailings flow:

Rupture mechanism  
Height and width of the breach  
**Type of retention dam**  
**Volume of the impoundment**  
**Downstream topography (and conditions)**  
**Presence of pond**  
Degree of consolidation of the tailings  
Undrained shear strength of the tailings  
Lenses of hardpan in the tailings  
Erodibility of the tailings  
Liquefaction of the tailings (static or dynamic)  
Residual undrained shear strength of the tailings

## Quantified using:

- Cause of rupture
- Flow classification
- **Type of dam**
- **Volume of Impoundment**
- **Downstream gradient**
- **Presence of pond**
- Type of tailings
- Status of impoundment
- Occurrence of liquefaction

# Tailings Dam Breach Modelling Classes

		Potential for tailings to runout of the breach area as a result of liquefaction (seismic or static)	
		Yes	No
Presence of free water in area of breach	Pond near crest of dam	1A: Dam break method with flow of liquefied tailings contributing additional volume of material released	1B: Dam break method with tailings eroded, transported and deposited by flow of water
	No pond or pond far from crest	2A: Slope failure with debris flow or mud flow (degree of saturation)	2B: Slope failure

Liquefaction of tailings – could be induced by (i) a seismic event associated with a dam breach (either causing or following) and/or (ii) by shear strains in the tailings as a result of the dam breach.



# CDA Further Refined the Analyses by Subdividing the Flow Classification and the Type of Tailings

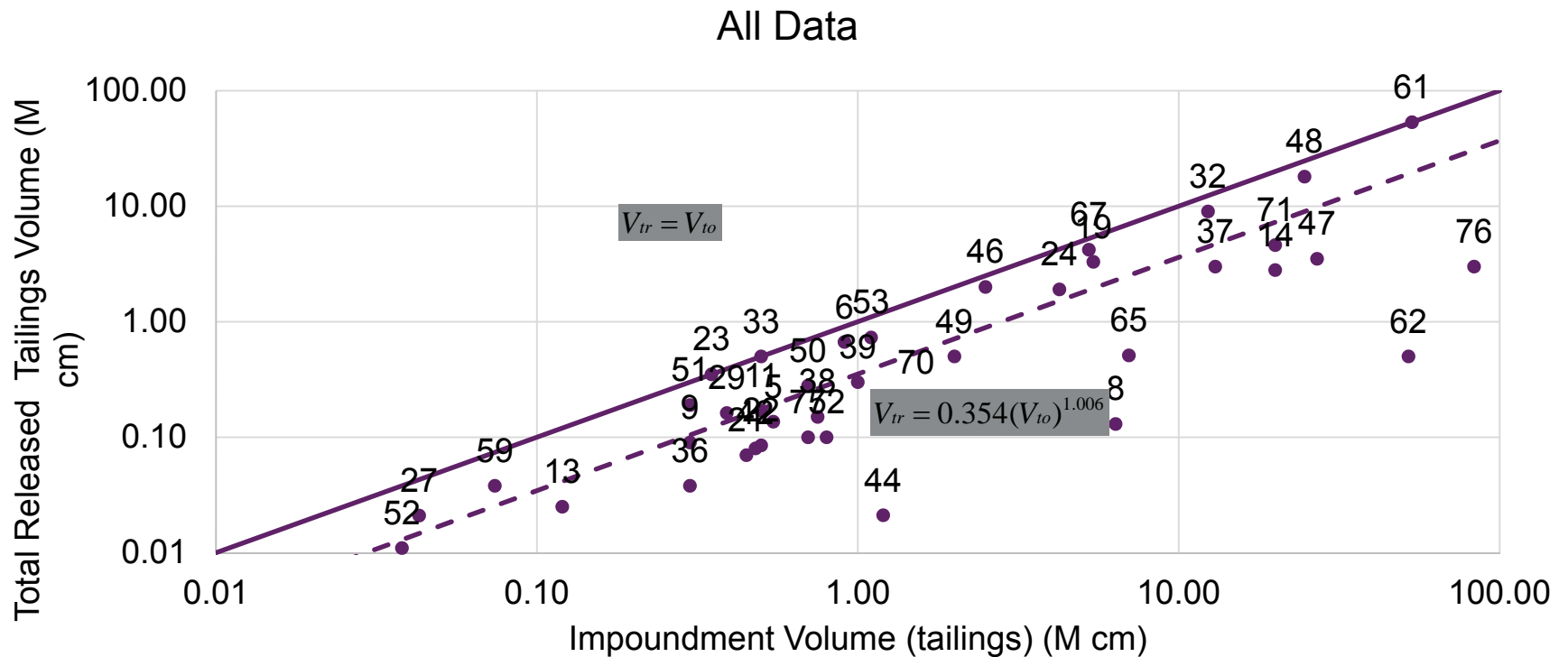
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- Flow:
    - ▶ 1A – Flow of Water and Liquefied Tailings
    - ▶ 2A – Debris or Mud Flow
    - ▶ 1B – Flow of Water with Eroded tailings
    - ▶ 2B – Slope Failure
    - ▶ 0 – Unknown
  - Type of Tailings:
    - ▶ Soft
    - ▶ Hard
    - ▶ Coal
    - ▶ Unknown
-

# Total Released Tailings Vol. vs Impounded Tailings Vol.

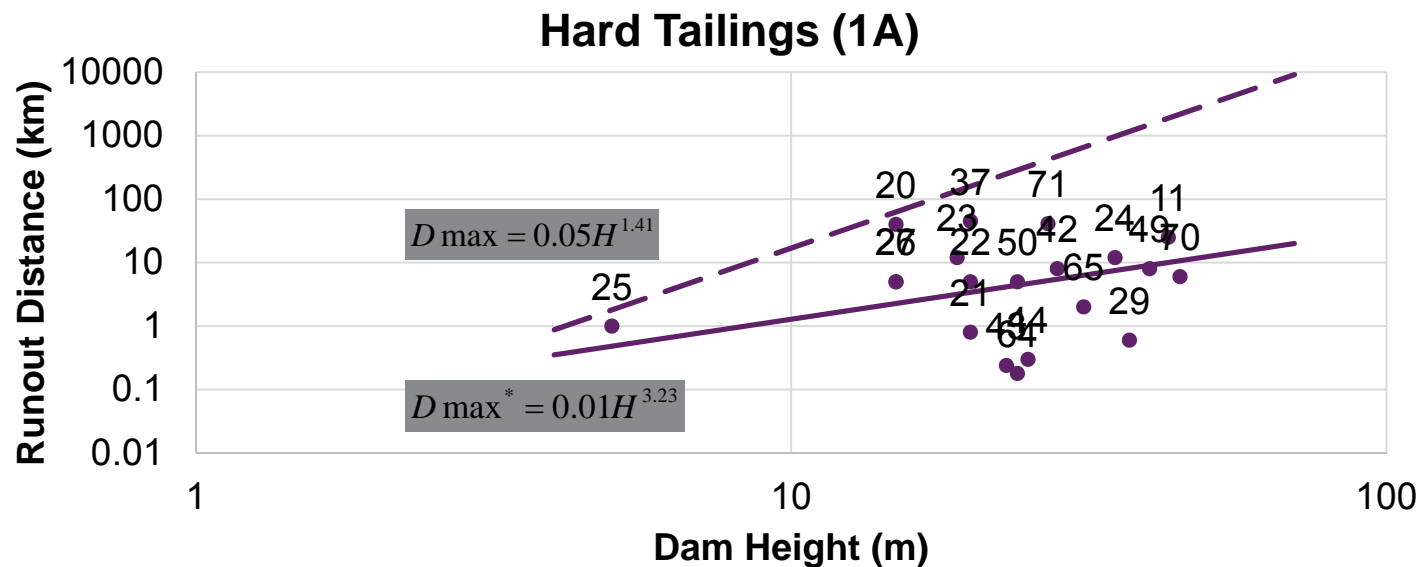
## All Classes



➤ Mount Polley Failure (2014) = 76

# Run-out Distance vs Height (cont'd)

## Hard Rock Tailings – Class 1A: Pond and Liquefied Tailings

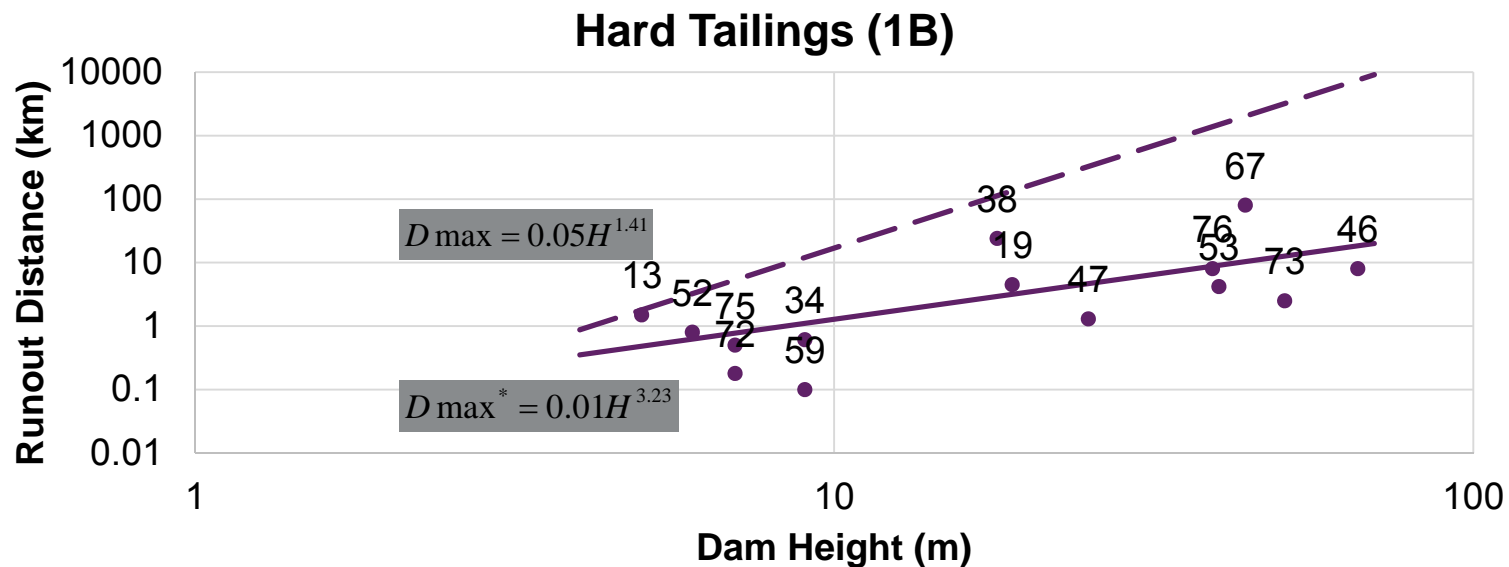


### Data tends toward lower curve

- The Samarco failure, although not presented in the plotted data, would be located in the upper right portion of the graph for case 2A. Dam height = 100 m, runout distance of 660 km and was truncated by the ocean.

## Run-out Distance vs Height (cont'd)

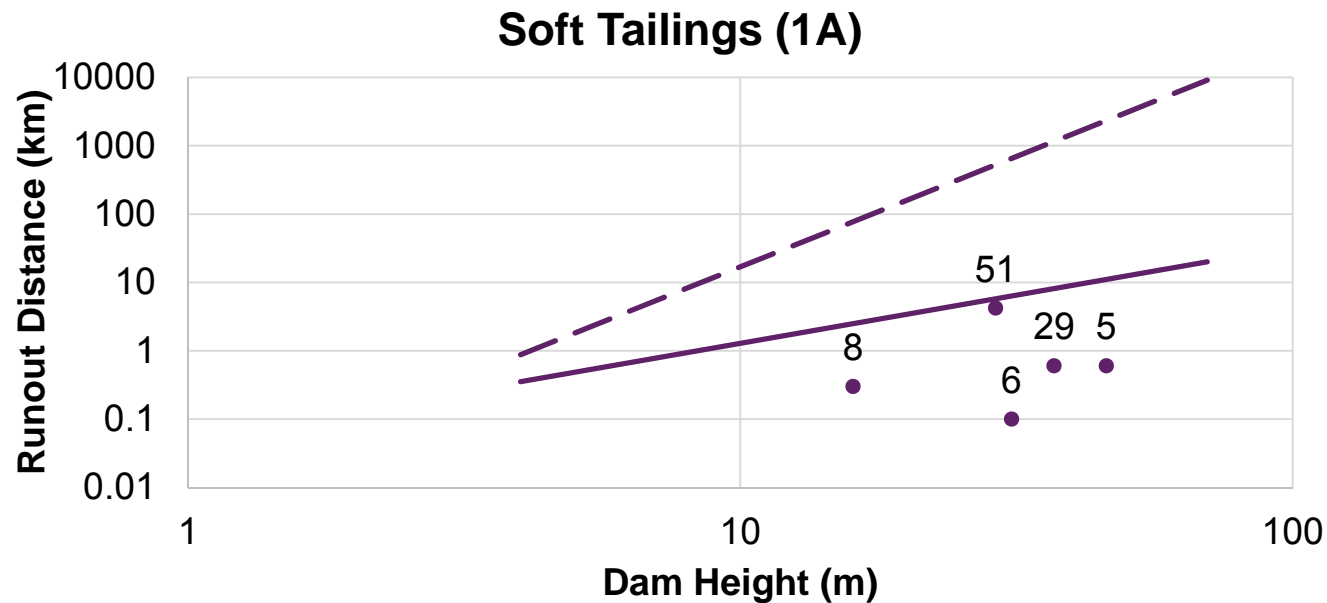
### Hard Rock Tailings – Class 1B: Pond and No Liquefied Tailings



- Mt Polley is Case 76, truncated by a lake tends toward lower regression line.

## Run-out Distance vs Height (cont'd)

### Soft Rock Tailings – Class 1A: Pond and Liquefied Tailings





## The CDA Dam Breach Working Group

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**The expanded data base of dam failures presented above has been compiled by the CDA Dam Breach Working Group headed by Michael James.**

**An updated version of the data base will be presented at this years CDA annual conference to be held October 14 – 20, 2017  
In Kelowna, BC**

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# How the CDA Classification Affects Design - Flooding Criteria



**Table 3-2. Target Levels for Flood Hazards, Standards-Based Assessments, for Construction, Operation, and Transition Phases**  
(For Initial Consideration and Consultation Between Owner and Regulator)

Dam Classification	Annual Exceedance Probability – Floods (note 1)
Low	1/100
Significant	Between 1/100 and 1/1,000 (note 2)
High	1/3 Between 1/1,000 and PMF (note 3)
Very High	2/3 Between 1/1,000 and PMF (note 3)
Extreme	PMF (note 3)

Notes:

Acronyms: PMF, Probable Maximum Flood; AEP, annual exceedance probability

1. Simple extrapolation of flood statistics beyond  $10^{-3}$  AEP is not acceptable.
2. Selected on basis of incremental flood analysis, exposure, and consequences of failure.
3. PMF has no associated AEP.

**SA50**

Changed to Affects

Small, Andy, 4/25/2017



# How the CDA Classification Affects Design

## - Earthquake Conditions



Table 3-3. Target Levels for Earthquake Hazards, Standards-Based Assessments, for Construction, Operation, and Transition Phases (For Initial Consideration and Consultation Between Owner and Regulator)

Dam Classification	Annual Exceedance Probability – Earthquakes (note 1)
Low	1/100 AEP
Significant	Between 1/100 and 1/1,000
High	1/2,475 (note 2)
Very High	1/2 Between 1/2,475 (note 2) and 1/10,000 or MCE (note 3)
Extreme	1/10,000 or MCE (note 3)

Notes:

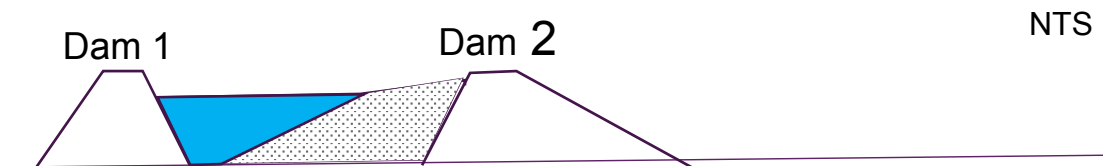
Acronyms: MCE, Maximum Credible Earthquake; AEP, annual exceedance probability

1. Mean values of the estimated range in AEP levels for earthquakes should be used. The earthquake(s) with the AEP as defined above is(are) then input as the contributory earthquake(s) to develop the Earthquake Design Ground Motion (EDGM) parameters as described in Section 6.5 of the *Dam Safety Guidelines* (CDA 2013).
2. This level has been selected for consistency with seismic design levels given in the National Building Code of Canada.
3. MCE has no associated AEP.

# Example Classification

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Consider Dam 2 during operation.



## Dam 1

- **Crest elevation 97 m**
- **Max height 50 m**
- **Pond against dam**
- **Spillway for 1 in 1000 year event at 95 m**
- **Core and rockfill shells**

## Tailings:

- Non acid generating
- Metal leaching

## Dam 2:

- **Crest elevation 97 m**
- **Max height 50 m**
- **Compacted tailings sand structure**
- **Internal drains**
- **No fouling occurring**

## D/S Env:

- Small brook running into a river in a narrow valley
  - Important fish habitat
  - Community of 5000 people in valley 5 km from dam
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## Example Cases

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**Flood induced failure (overtopping possible and credible) – Very High to Extreme**

**Fairweather failure (piping, seismic) - Extreme**



## Example Cases (cont'd)

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### **Near end of operations:**

- ▶ Tailings beach extends further away from Dam 2
- ▶ Pond lowered

**Flood induced failure (overtopping possible and credible) – Very High to Extreme**

**Fairweather failure (piping, seismic) - Extreme**



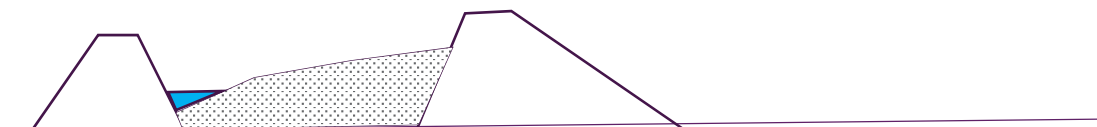
## Example Case (cont'd)

### After closure:

- ▶ Crest of Dam H2 raised 2 m
- ▶ PMF Spillway installed at Dam H1
- ▶ Pond further lowered

**Flood induced failure (overtopping not credible, internal erosion not credible) – Remains at Very High to Extreme because of population at risk and environmental consequences.**

**Fairweather failure (piping not credible, seismic not credible) – Remains at Extreme because population at risk and environmental consequences.**



## Role of Risk Assessment – Amec FW Approach

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- **Conduct risk assessment to properly indicate the level of risk associated with the dam.**
  - **For the example case, the only credible failure mode could be localized erosion and slumping of the toe during a significant precipitation event**
  - **Non-credible failure modes are not considered in the risk assessment**
  - **Could have an Extreme classification dam with a Low Risk profile. (Example above following closure)**
  - **Summarizes the essential messages about the dam.**
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# Emergency Response

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- **“Decouple” from the Classification.**
  - **Assumes only credible failure modes.**
  - **Conduct dam breach for credible failure modes in support of the emergency response plan.**
  - **Example case: do not need to alarm downstream residents.**
  - **Makes emergency planning more realistic and meaningful to regulators and stakeholders (*“This will never happen, so why do I need to care?”*).**
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## Mine Waste Facility – When a dam is no longer a Dam

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If following closure:

- There is no free water on the surface.
- The tailings are not saturated
- The tailings are shown to be non-flowable if the structure fails.

Then:

**The facility is no longer considered or classified as a “dam” and CDA would put it in Class 2B and classify the facility as a mine waste facility. Runout and downstream affects are no longer a concern and the facility can now be managed as a closed waste dump.**

Note:

**Amec Foster Wheeler has used this approach at several sites, However; CDA has not yet developed the guidance for this and it has not been adopted in regulation.**

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# Q&A

