
Grasberg, 2003
Topics in Slope Engineering
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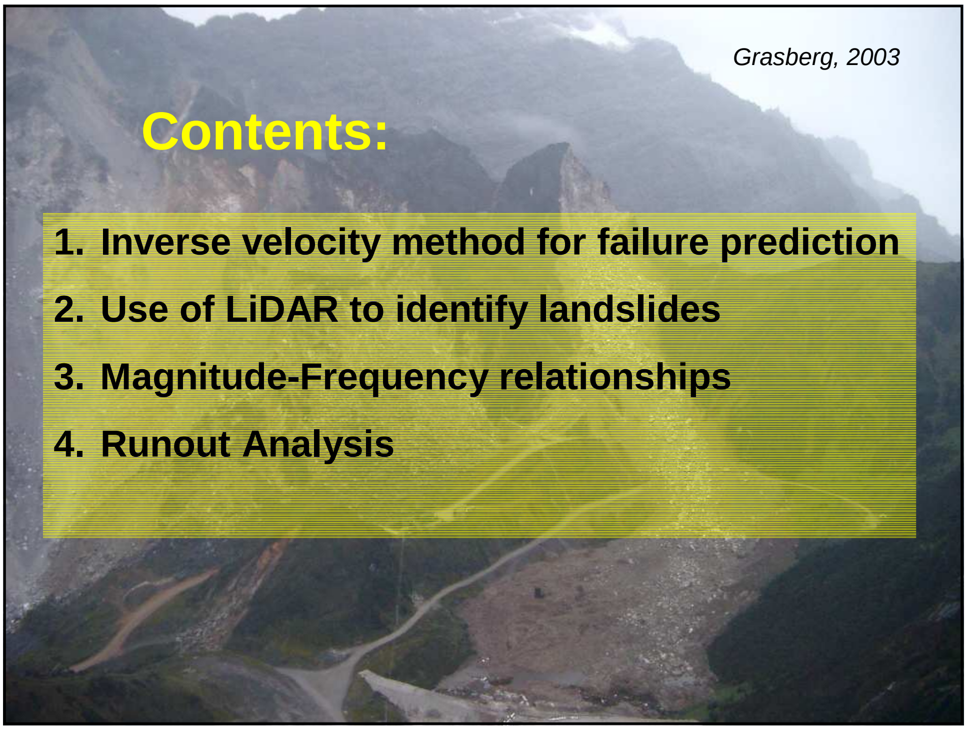
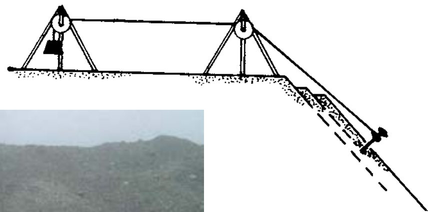

Grasberg, 2003
Contents:
1. Inverse velocity method for failure prediction
2. Use of LiDAR to identify landslides
3. Magnitude-Frequency relationships
4. Runout Analysis

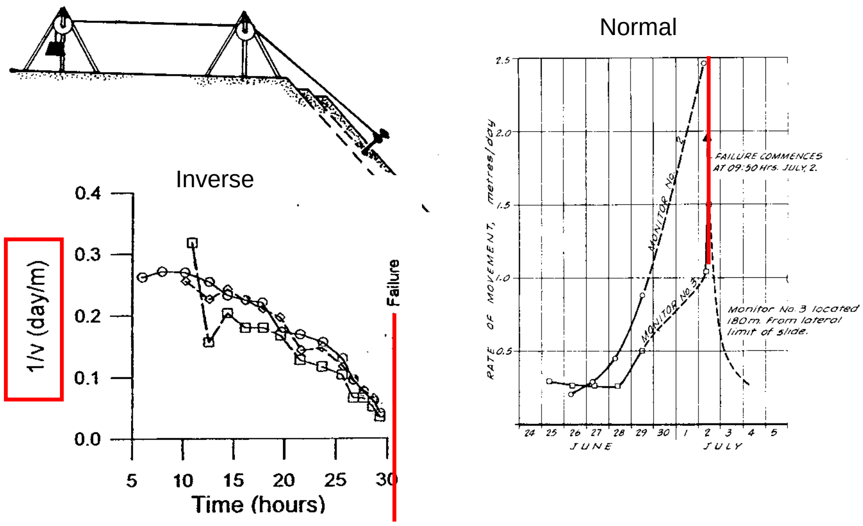
Coal Mine Waste Dumps

Wire extensometer

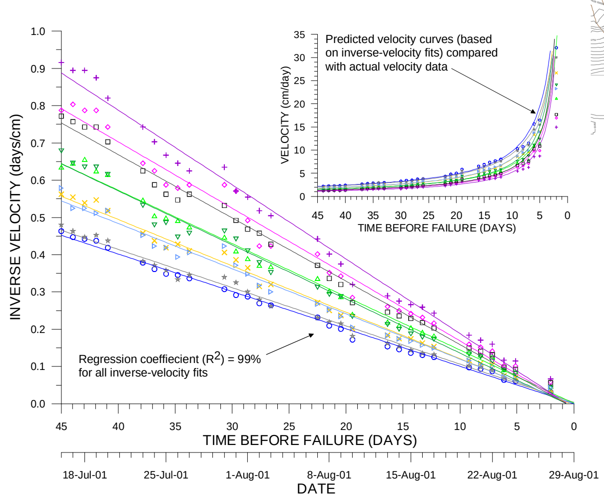


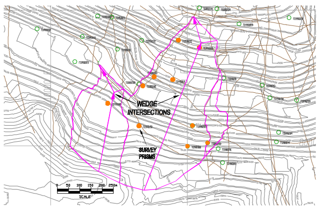
With data logger

Inverse Velocity Method (Fukuzono, 1985)

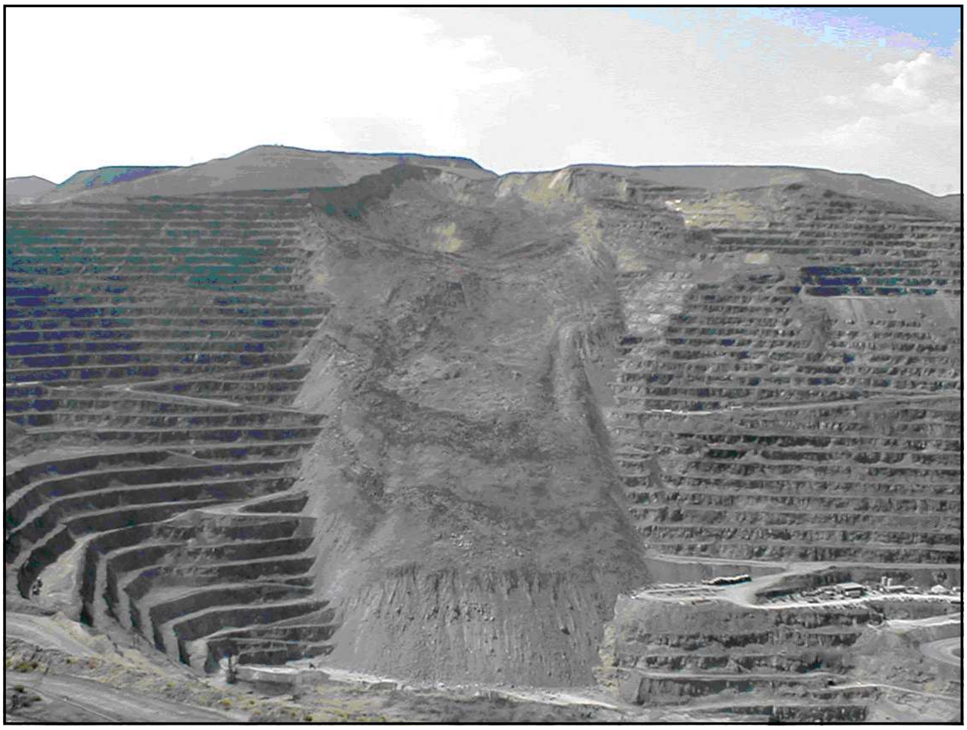


Inverse Velocity Method, Open Pit Mines

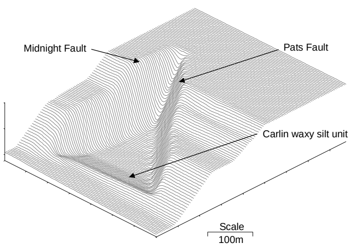




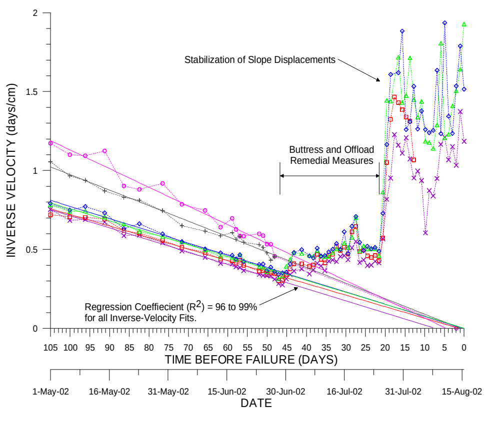
18 million m^3 pit slope failure predicted (Rose and Hungr, 2006)



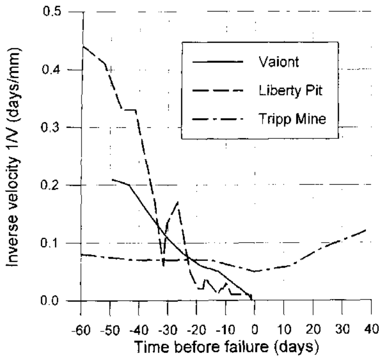
Use of inverse velocity to monitor stabilization progress (Rose and Hungr, 2006)



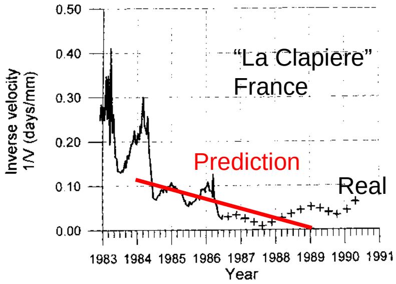
Two faults and a pre-sheared silt layer, 3 million m³ (CLARA_W 3D Model)



Inverse Velocity Method, more examples



Tripp Mine: slow failure

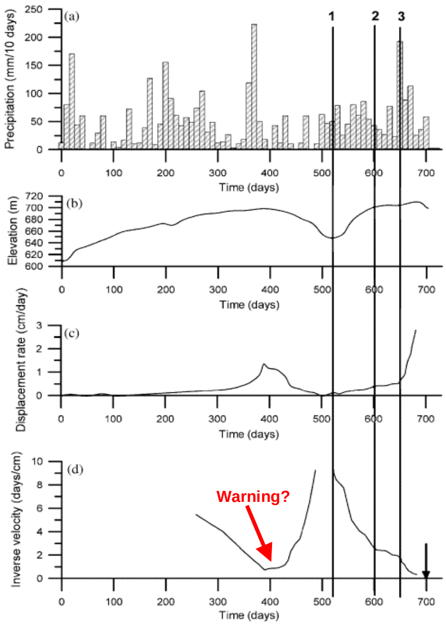


Vaiont

Causes of Variation:

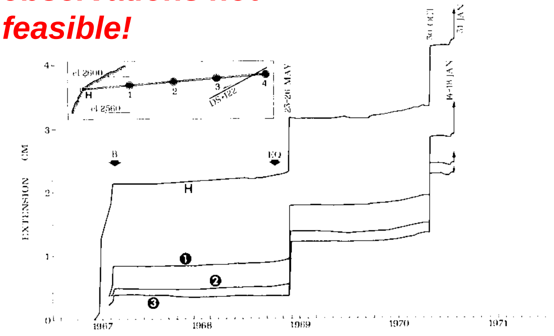
(Rose and Hungr, 2006)

1) Measurement error
2) Local movements
3) Periodic variation
4) Trend changes



Small rock slides, Brittle Failure

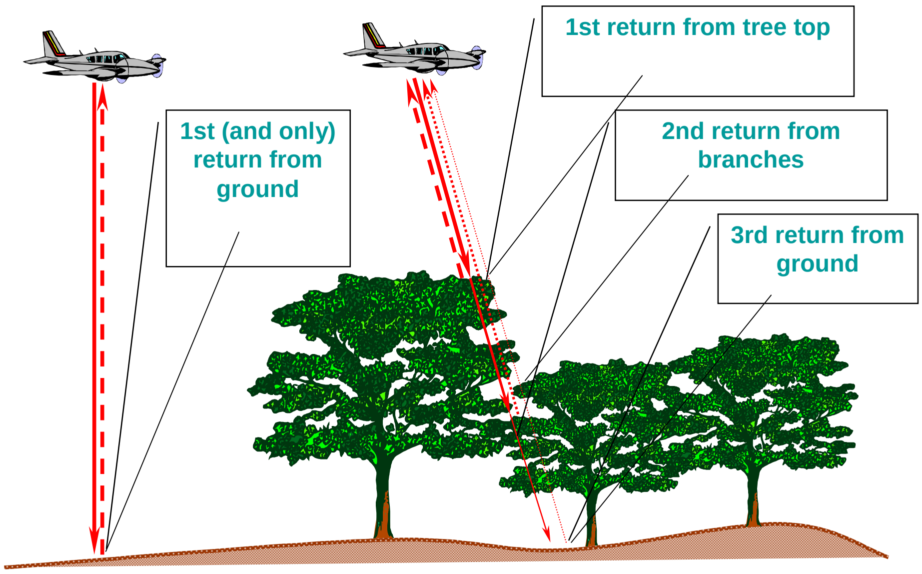
Failure prediction from displacement observations not feasible!

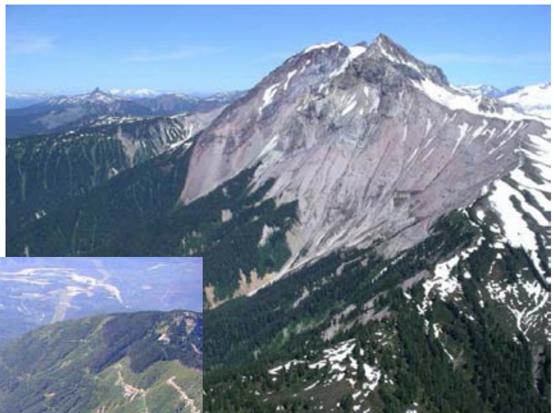


Libby Dam, Montana, 1971

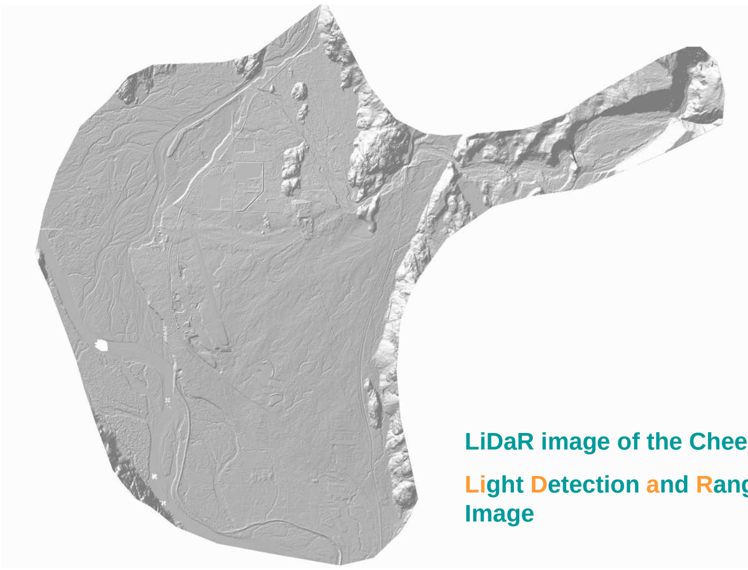
Prediction not feasible

Airborne LiDAR Survey (GEO, 2006)





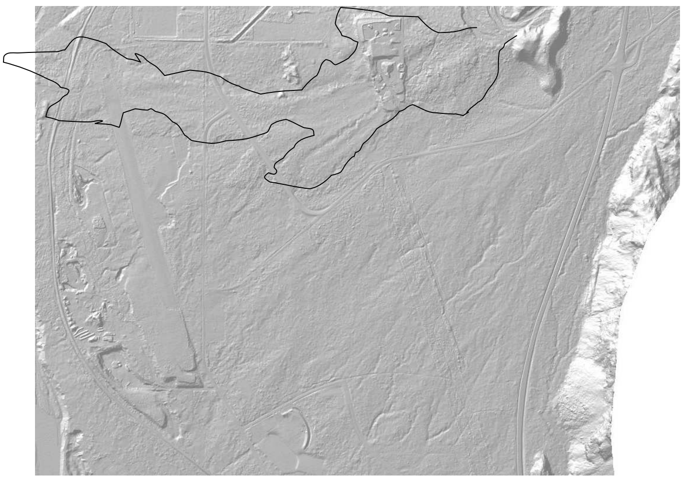
View down the Cheekye River towards the fan



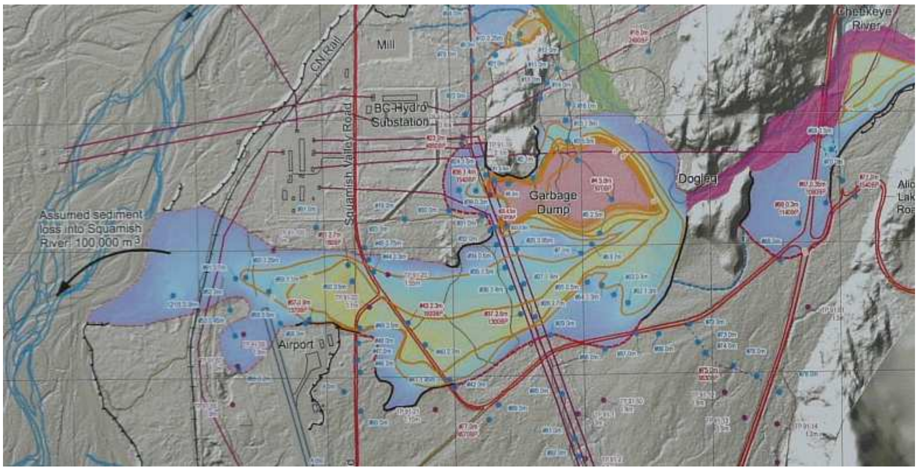
LiDaR image of the Cheekye fan

Light Detection and Ranging Image

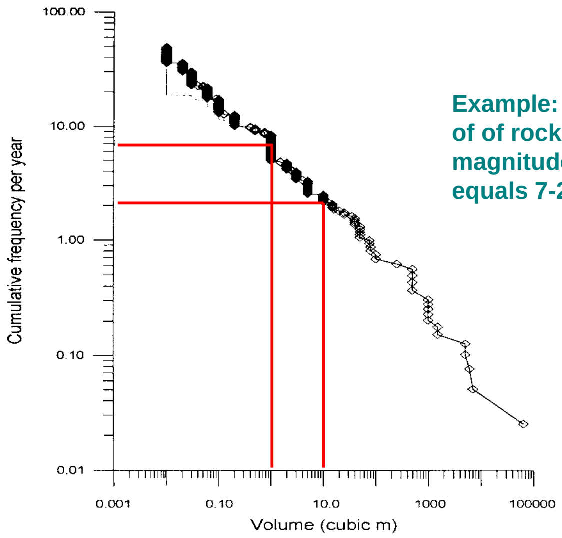
Cheakamus fan: debris flow deposit on the surface



Cheekye River, debris flow, 800 BP, 2.4 M m^3



Cumulative Frequency –Magnitude (CFM) curve



Example: annual frequency of of rock falls in the magnitude range 1 to 10 m^3 equals 7-2=5

Rockfall records, BC Hwy 99 Vancouver-Squamish

(Guttenberg-Richter method)

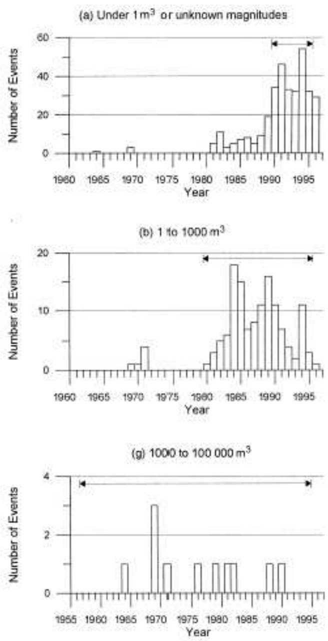
$$f_i = \frac{1}{T_i}$$

Incremental frequency

$$F_i = \sum_{i=1}^{j} f_i$$

Cumulative frequency

(Hungr et al., 1998)



Range of magnitudes

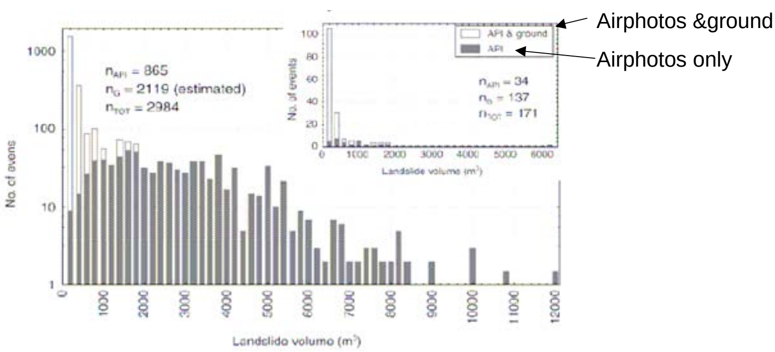
30 m³

60 000 m³

Alternative: Histogram approach

Example: frequency of debris avalanches in a region north of Vancouver (Brardinini and Church, 2003).

Histogram depends on bin size, arithmetic vs. logarithmic binning

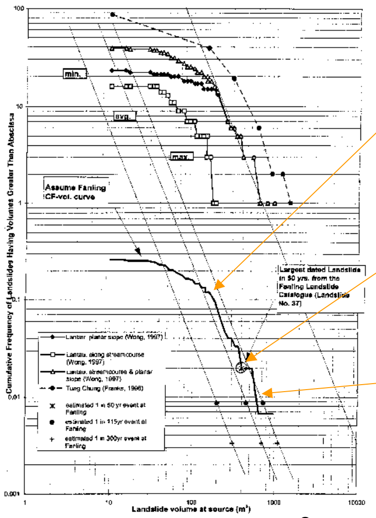


Censoring: CFM curves for debris avalanches

Lantau Island, Hong Kong, Wong et al., 1998)

Cumulative frequency

(scales to the size of the area)



"Rollover" (Censoring)

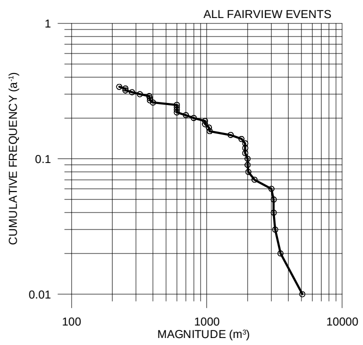
Anchor

Linear part

Magnitude (m^3)

"Rollover" may be controlled by the size of the slope

Container port, Prince Rupert, NW B.C.



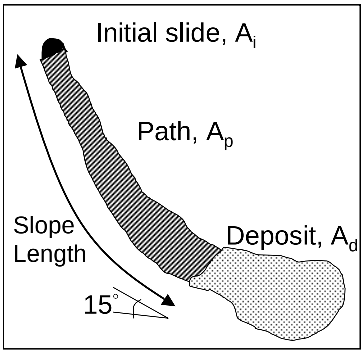
Independence:

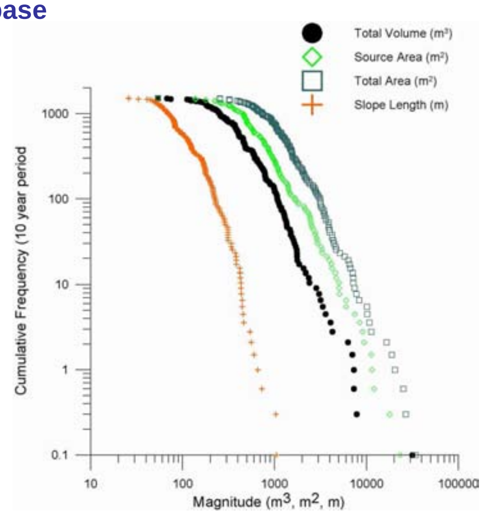
CFM curves for debris avalanches,

Queen Charlotte Islands Database

(data from Wise, 1996)

Conclusion: M is not an independent quantity





Source Area = $A_i + A_p$

Total Area = $A_i + A_{p+} A_d$

Stationarity

Vargas state, Venezuella

December 1999 ←

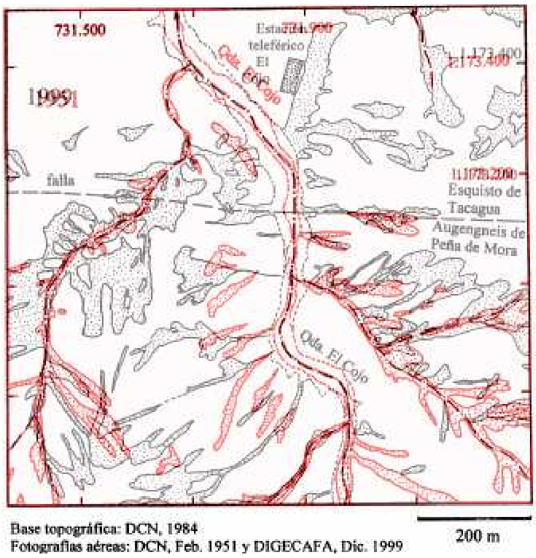
February 1951 →

Vargas state, Venezuella

Quebrada El Cojo:

1951

1999



"Depletion theory": Landslides are less likely to occur (or impossible), where they have occurred previously (Sarno)

Homogeneity (clustering)

Cluster extent controlled by:

1) Pre-conditioning factors 2) Rainfall distribution (New Zealand)

- **Topography**
- **Geology**
- **Land use**

Summary:

Frequency-Magnitude relationships are useful, but user must consider the basic assumptions of statistics:

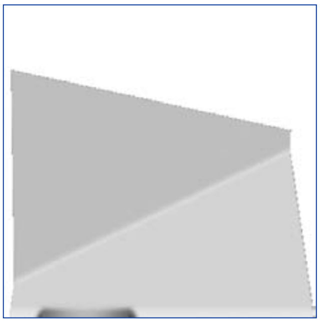
- **Censoring**
- **Independence**
- **Stationarity**
- **Homogeneity**

Model verification

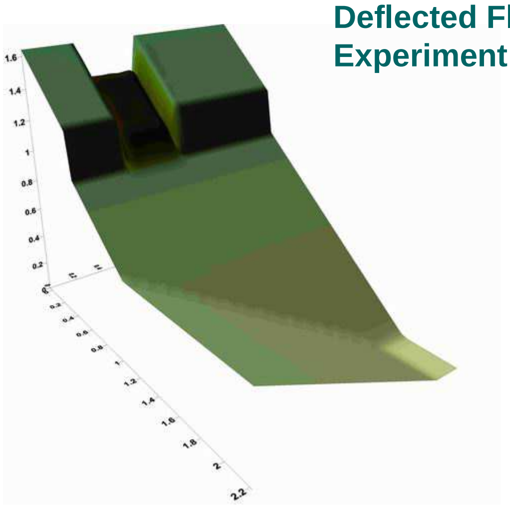
A "correct" model is one that produces verifiably accurate results for a range of geometries and simple, independently derived, material properties.

Model verification exercises rely on physical laboratory model cases, with simple materials whose rheological behaviour is well- understood, such as water, oil and dry granular material

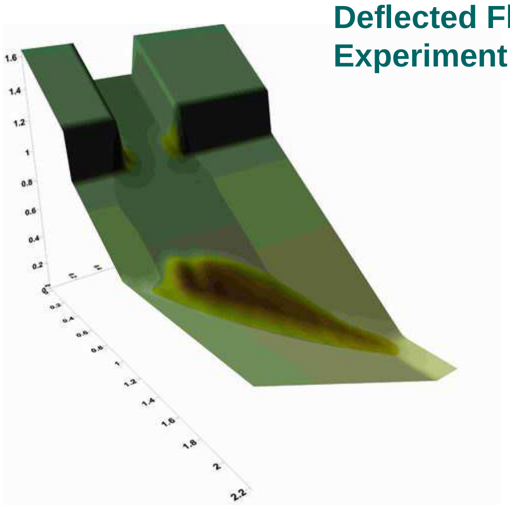
Deflected flow experiment



Deflected Flow Experiment



Deflected Flow Experiment



Model Calibration:

Purpose: Find a set of parameters suitable for the case studied

1. Select cases similar to the slide in question
2. Run program to obtain requisite runout
3. Compare debris thickness, velocity distribution
4. Select the “best fit” rheology and parameters
5. Use the best fit model and parameters for prediction

“Calibrated” model should preferably fit several similar cases (not just one)

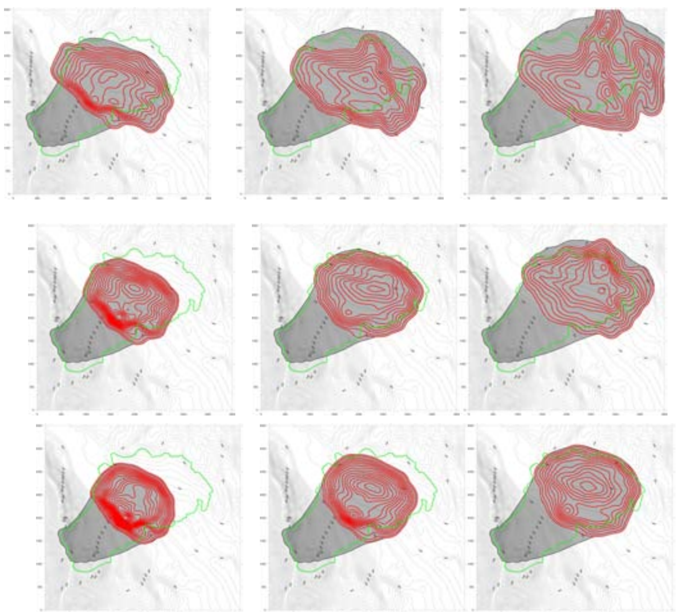
Frank Slide calibration matrix for the Voellmy Model

ξ=250 ξ=500 ξ=1000

f=0.05

f=0.1

f=0.15

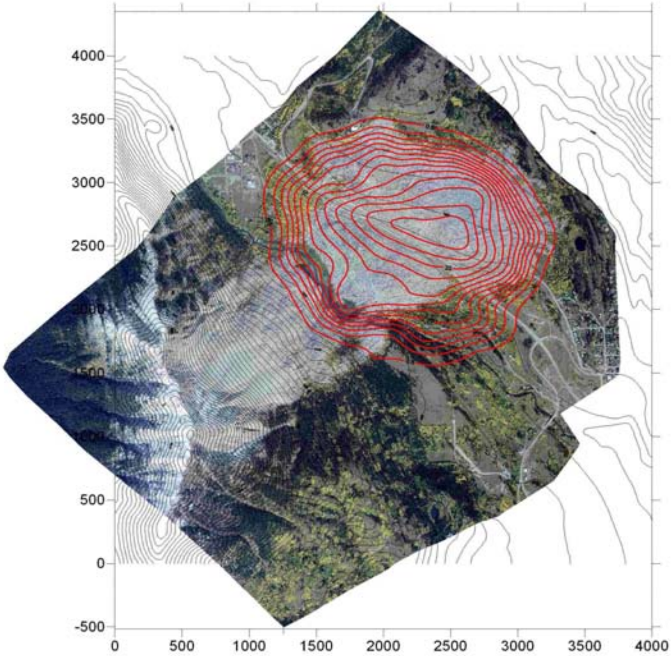


Frank Slide, Alberta, Canada

Calibrated Model

Voellmy

ξ=500. f=0.1

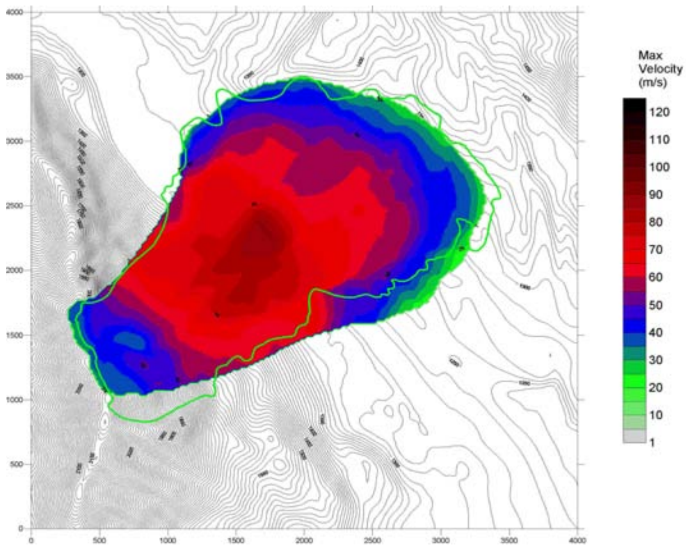


Frank Slide, Alberta, Canada

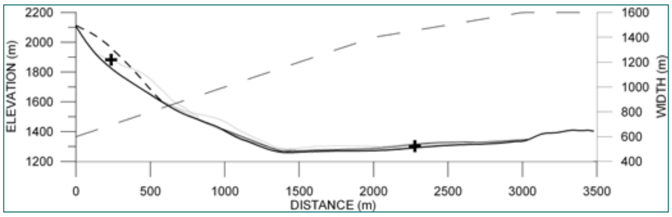
Calibrated Model

Voellmy

ξ=500. f=0.1

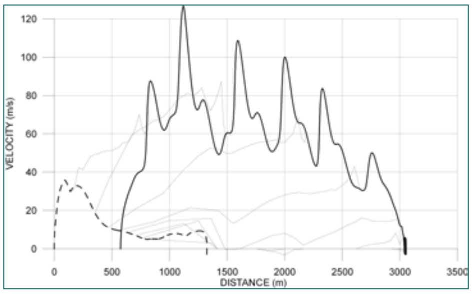


Frank Slide, Alberta, Canada



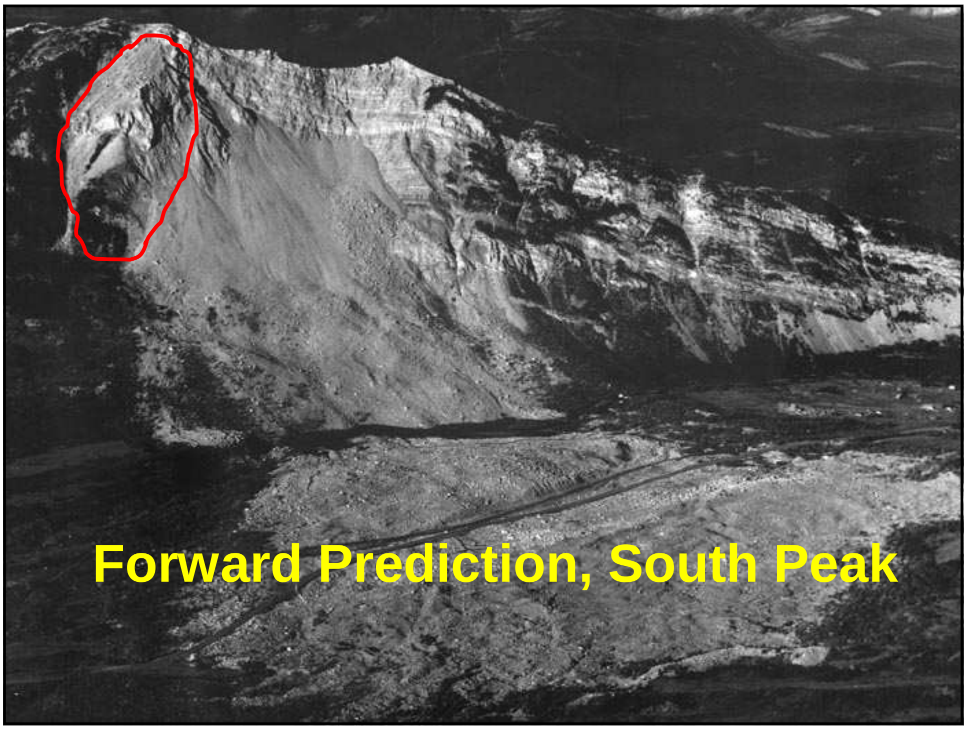
2D

Calibrated Model



Voellmy

ξ=500. f=0.1




With better tools, we can do more to reduce risks from landslides.
Thank you
EOS
UBC