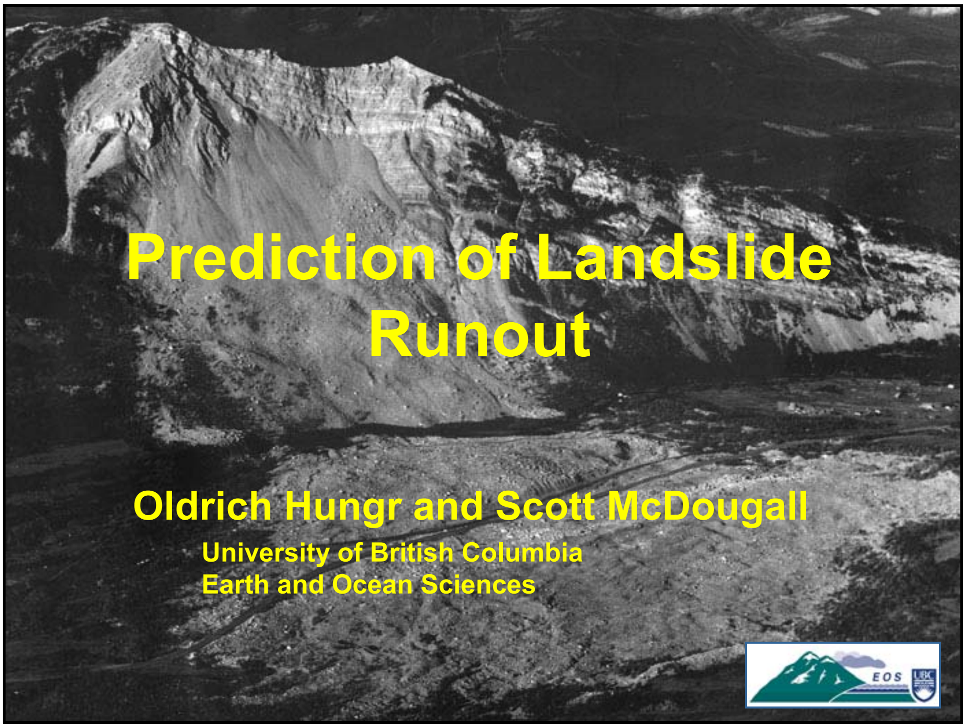
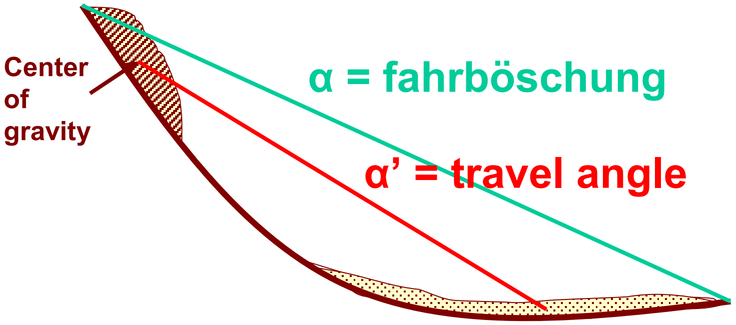


Prediction of Landslide Runout

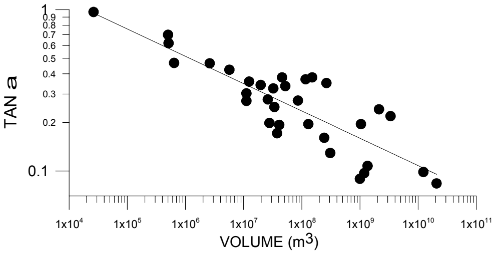
Oldrich Hungr and Scott McDougall
University of British Columbia
Earth and Ocean Sciences

Fahrböschung (travel angle)

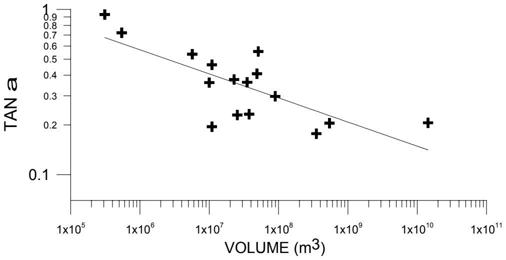


Theoretically, in a frictional material (dry sand, broken rock), the travel angle should equal the angle of friction, φ.
The angle α equals approximately α’.
If the travel angle is less than φ, pore-pressure is involved

Mobility increases with volume

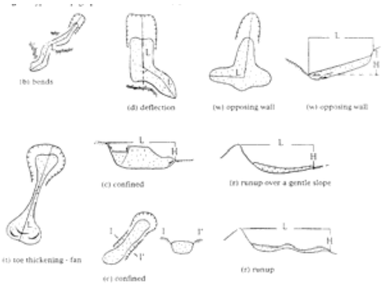


"Scheidegger plot" (1973)

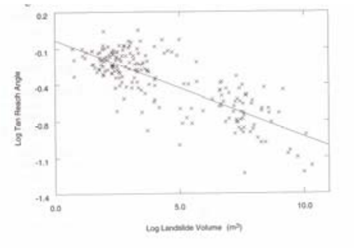


Center of gravity displacement (Hungr, 1981)

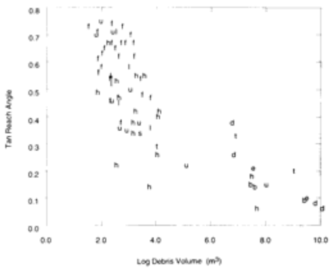
Corominas (1996)



All landslides

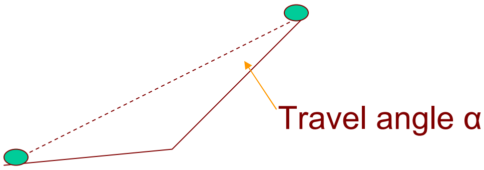


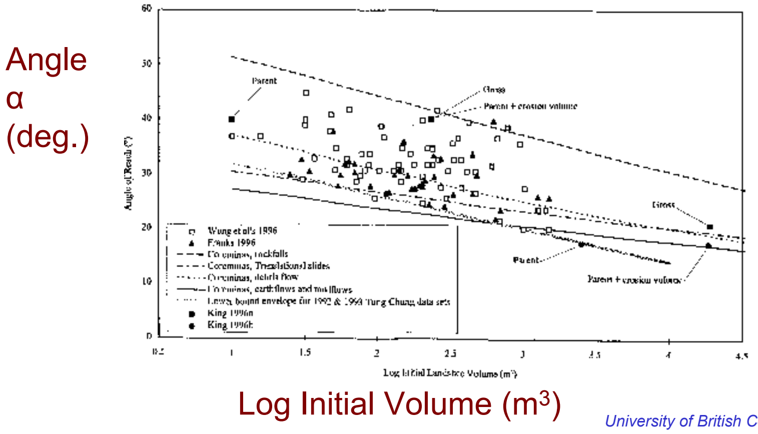
Debris flows



Debris flows in Hong Kong

(Wong et al., 1997)





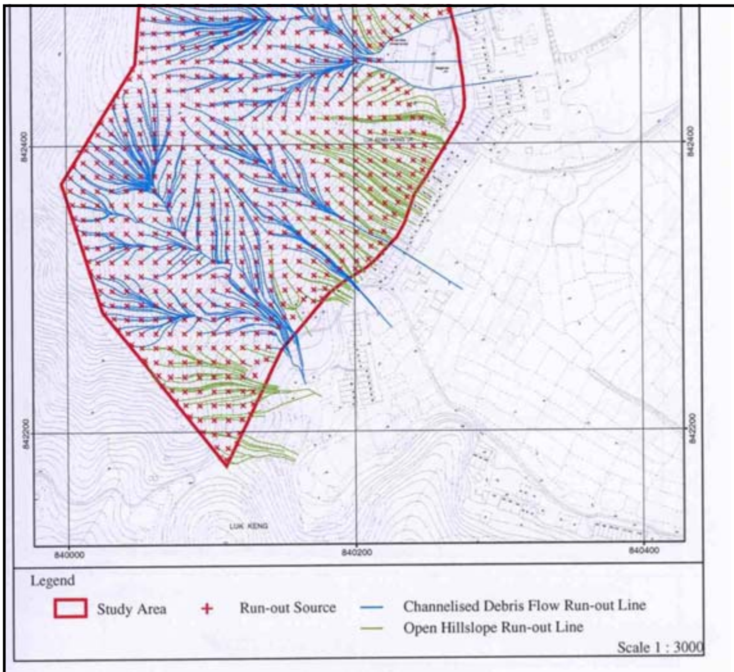


Figure 38 - Landslide Run-out Assessment

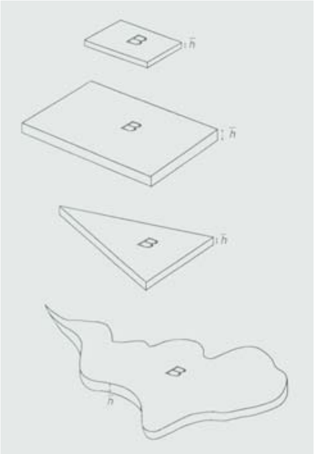
GIS-based susceptibility analysis

Hong Kong, 2003

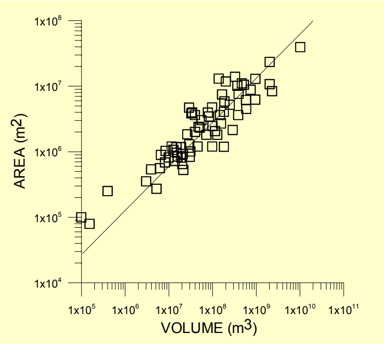
Delivery paths

Empirical Methods

- **area-volume relationships**

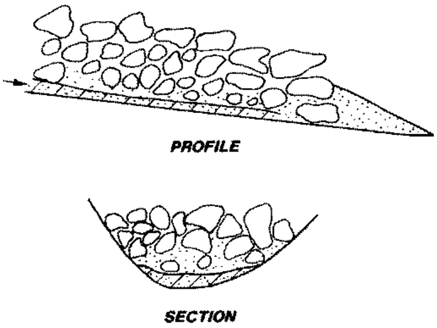


for geometrically similar deposits:
area ∝ volume$^{(2/3)}$

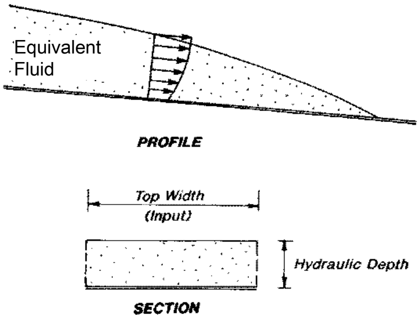


(Li 1983; Iverson et al. 1998)

Dynamic modelling:
concept of equivalent fluid



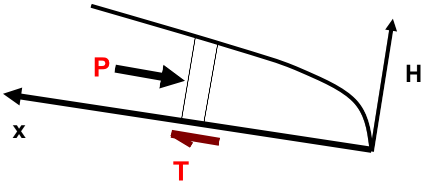
Prototype



Model

St.Venant Equation, Lagrangian

(Savage and Hutter, 1988)



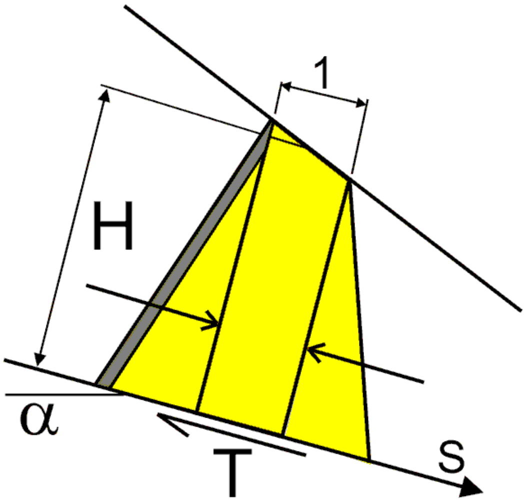
Moving
Coordinate
system

$$\frac{dv}{dt} = g\sin\alpha - \frac{T}{\rho H} + gk\cos\alpha\,\frac{dH}{dx}$$

Acceleration =

Gravity – friction + pressure term (P)

Dynamic equilibrium of a column



T = resisting stress

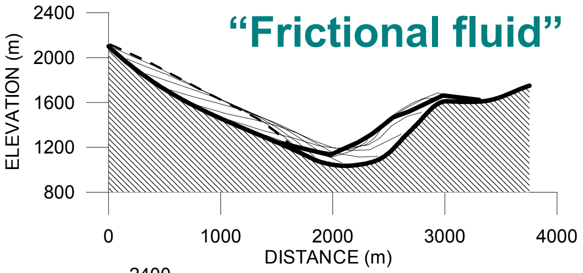
Pressure term:

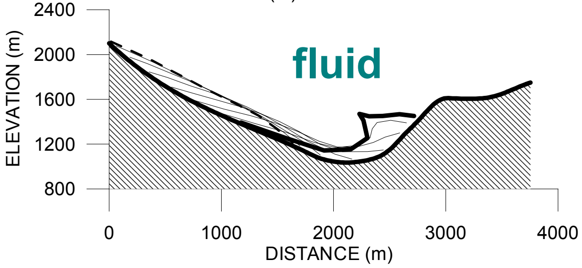
$$P = \gamma k\,\frac{dH}{ds}\,H\cos\alpha$$

***k* – lateral pressure coefficient**

Avalanche Lake runup,

Northwest Territories


“Frictional fluid”


fluid

Resisting force, T

Frictional:

$$T = (\sigma - u)\tan\phi$$

or: $T = \sigma \tan\phi_b$

Where Φ_b is the "Bulk Friction Angle (modified by pore-pressure

$$\tan\phi_b = (1 - r_u)\tan\phi$$

Resisting force, T

Plastic: $T = \tau$

Viscous: $T = \dfrac{3V\mu}{H}$

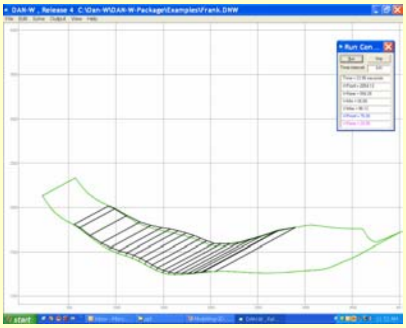
Bingham: Yield stress + viscous effect

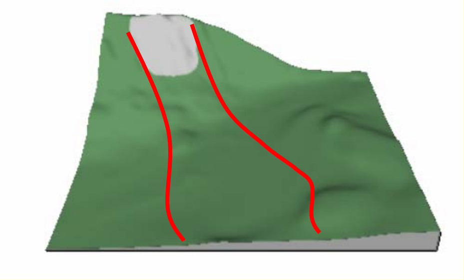
Voellmy: $T = \mu\sigma + \gamma\dfrac{V^2}{\xi}$

Simulate path width

Pseudo-3D

(Hungr, 1995)





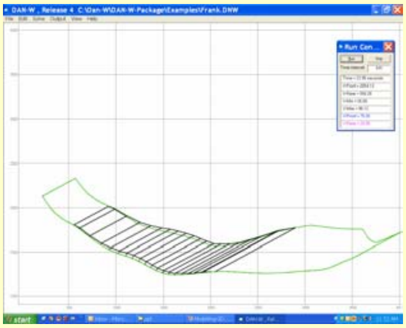
Simulate path width

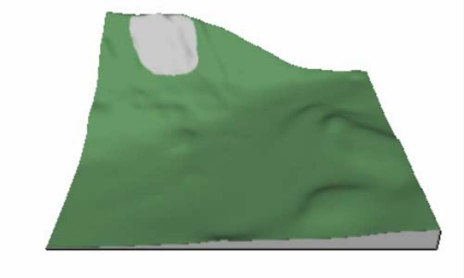
Pseudo-3D

(Hungr, 1995)

3D

McDougall and Hungr, 2004)

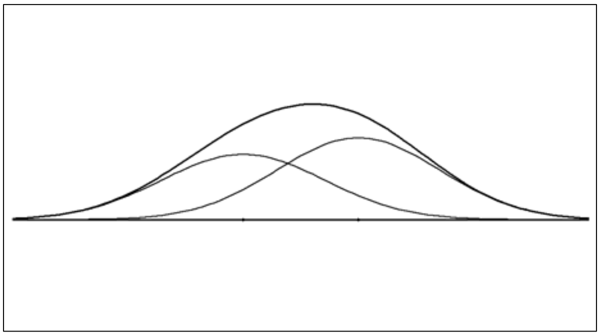




DAN 3D

- **the new model**

...based on "Smoothed Particle Hydrodynamics"...



Governing equations

Mass Balance

$$\frac{\partial h}{\partial t} + h\left(\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y}\right) = \frac{\partial e}{\partial t}$$

Momentum equilibrium

$$\rho h \frac{\partial v_x}{\partial t} = \rho h g_x + k_x \sigma_z \left(-\frac{\partial h}{\partial x}\right) + k_{yx}\sigma_z\left(-\frac{\partial h}{\partial y}\right) + \tau_{zx} - \rho v_x \frac{\partial e}{\partial t}$$

$$\rho h \frac{\partial v_y}{\partial t} = \rho h g_y + k_y \sigma_z \left(-\frac{\partial h}{\partial y}\right) + k_{xy}\sigma_z\left(-\frac{\partial h}{\partial x}\right) + \tau_{zy} - \rho v_y \frac{\partial e}{\partial t}$$

Acceleration =

gravity – friction – pressure - momentum correction

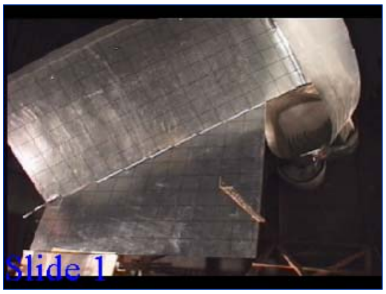
(McDougall and Hungr, 2004)

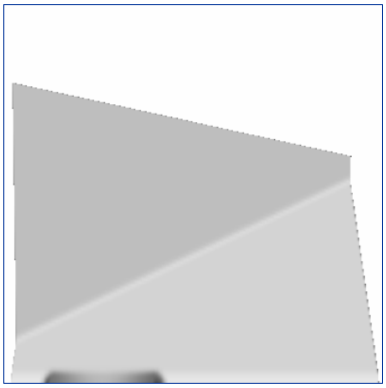
DAN3D

- model testing

DAN3D Model Verification

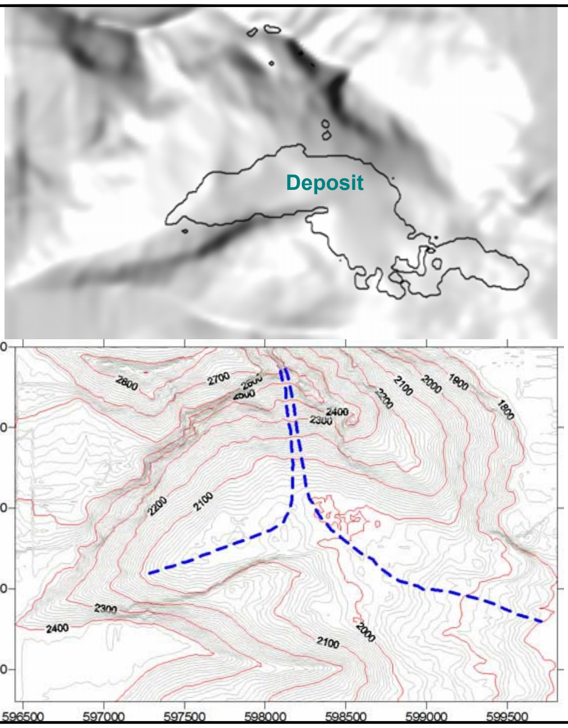
experiment #1





model

Eaux Froides rock avalanche, Switzerland (courtesy J.-D. Rouiller)



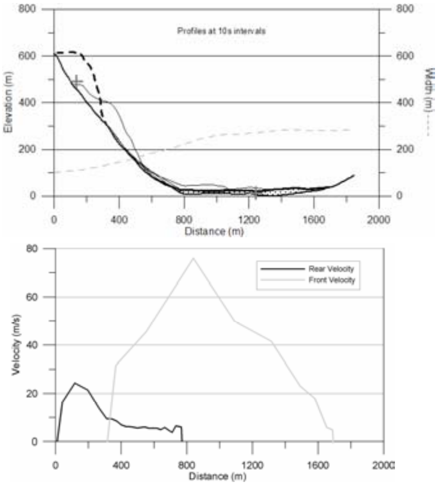
Eaux Froides

DAN-W

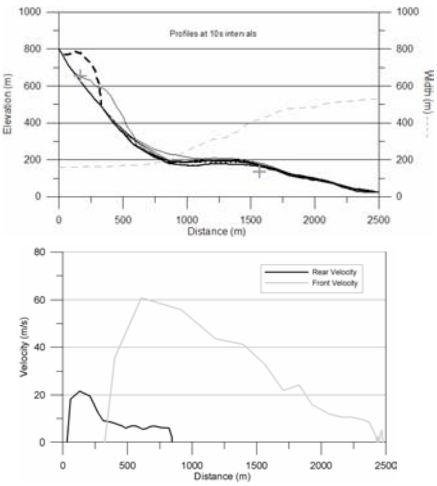
DAN-W paths

Eaux Froides: Voellmy ($\mu = 0.13$, $\xi = 450\ m/s^2$)

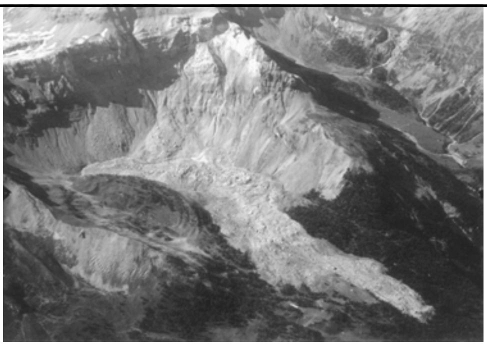
Left Side

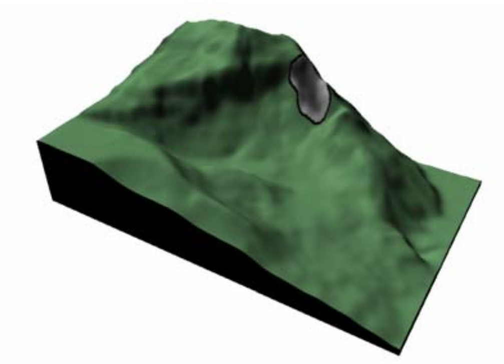


Right Side



Eaux Froides





Voellmy

$\mu = 0.13$

$\xi = 450\ m/s^2$

(DAN-W Calibrated)

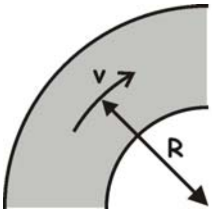
Model Calibration:

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

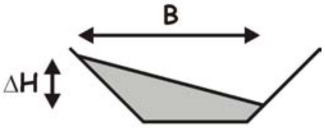
Estimation of velocity in the field

Forced Vortex Equation (superelevation)

$$\Delta H = B\frac{v^2}{Rg}$$



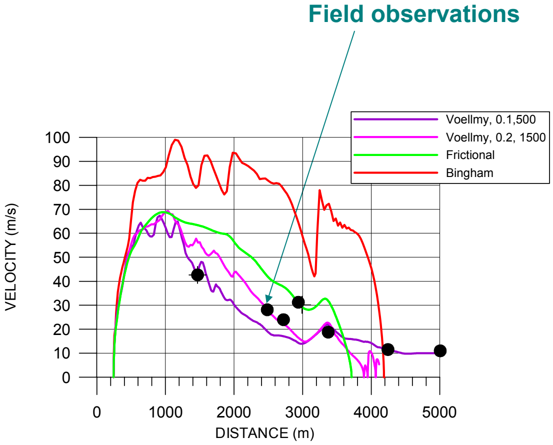
plan



x-section

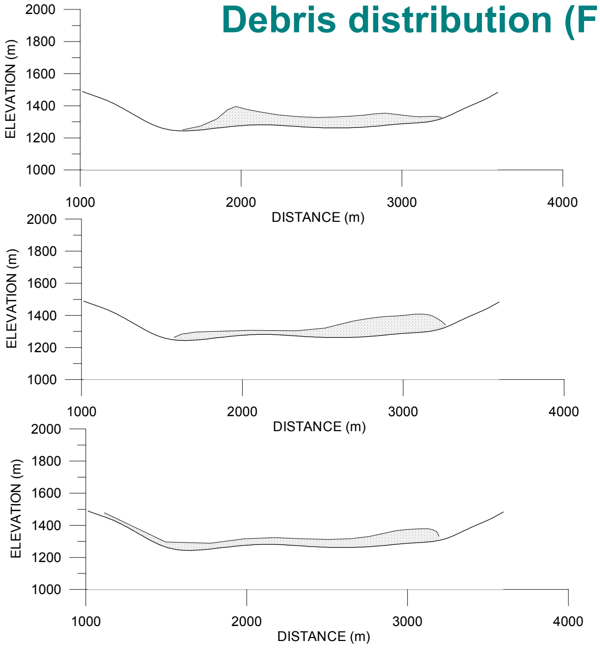
e.g.(Hungr et al. 1984)

Example back-analysis:
Mt. Cayley rock avalanche, 1983



Frictional: fi=30, ru=0.45
Bingham: tau=18kPa, viscosity=1 kPa.s

Debris distribution (Frank Slide)



Frictional

Voellmy

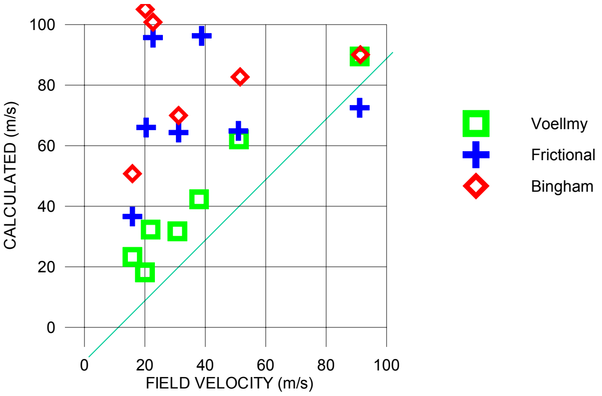
Bingham

Magnified 5x

Frank Slide debris

Velocity comparison

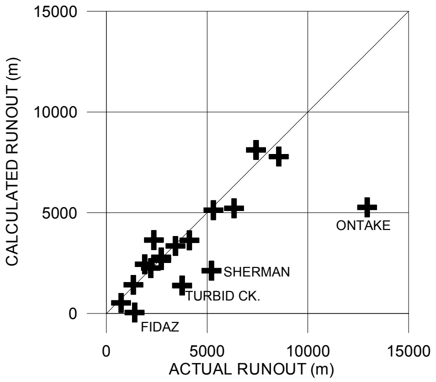
(23 rock avalanches Hungr and Evans, 1996)



“Opportunistic” field velocity estimates

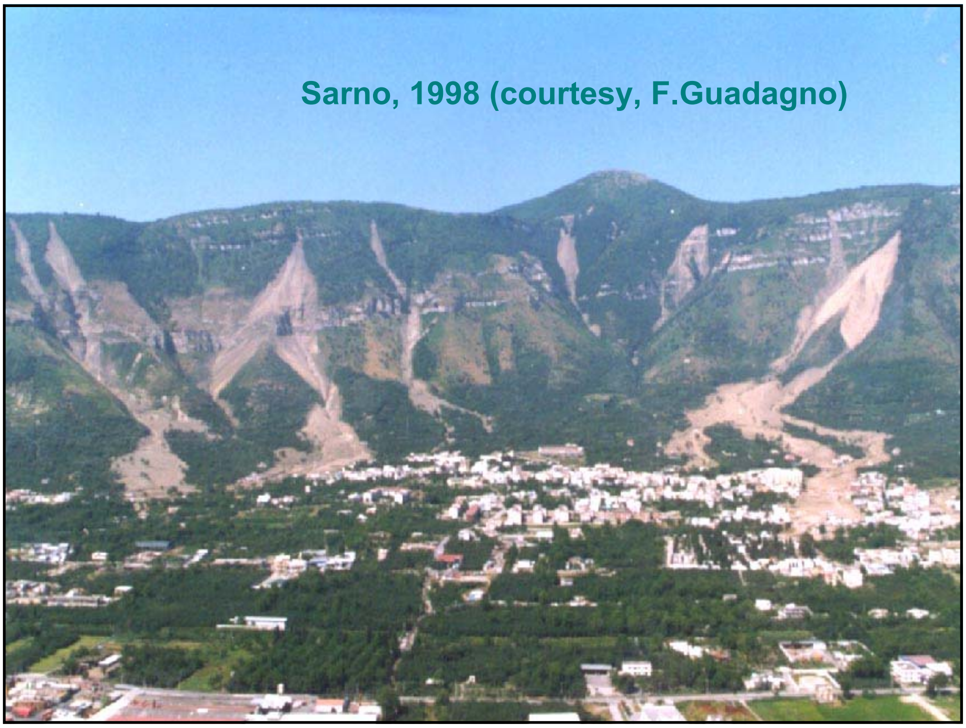
Voellmy model with fixed parameters

first – order prediction for rock avalanches



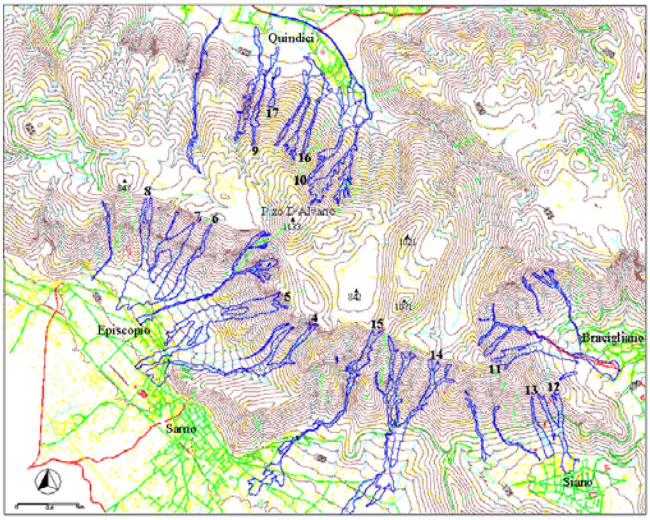
$\mu = 0.1$

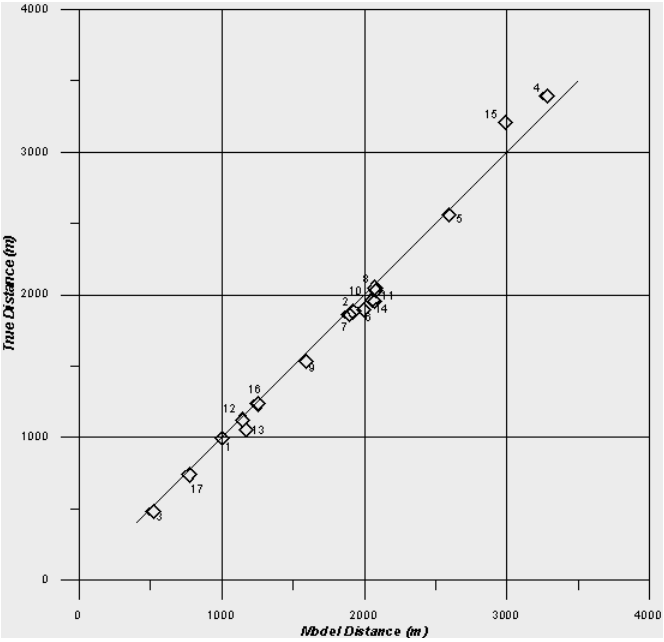
$\xi = 500\ m^2/s$



Sarno, 1998 (courtesy, F.Guadagno)

Map of Sarno area





Sarno: DAN back-analyses

f=0.07

Ksi=200

(Revellino et al.,2002)

Summary of Calibration results

1) Small, “dry” rock avalanches - frictional, $\Phi_b=30^\circ$
(e.g. Strouth et al., 2005)

2) Campania debris avalanches - Voellmy, $\mu = 0.07$, $\xi = 200$ m/sec^2
(Revellino et al., 2002)

3) “Normal” waste dump flow slides - frictional, $\Phi_b=20^\circ$
(Hungr et al., 2002)

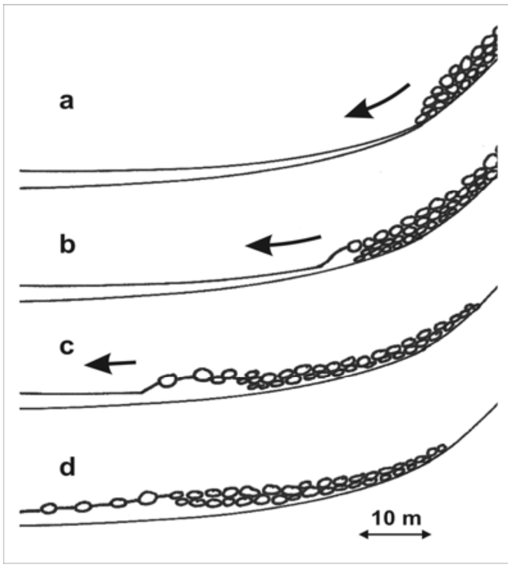
4) Debris avalanches in Hong Kong - frictional, $\Phi_b=20^\circ$
(Ayotte and Hungr, 2001)

5) Typical rock avalanches - Voellmy, $\mu = 0.1$, $\xi = 500$ m/sec^2
(Hungr and Evans, 1996)

6) Large rock avalanches involving ice - Voellmy, $\mu = 0.05$, $\xi = 1000$

7) Landslides involving clay - Bingham Model (Geertsema et al., 2006)

Material entrainment (Sassa, 1985)



Nomash Slide, Vancouver Island, B.C.

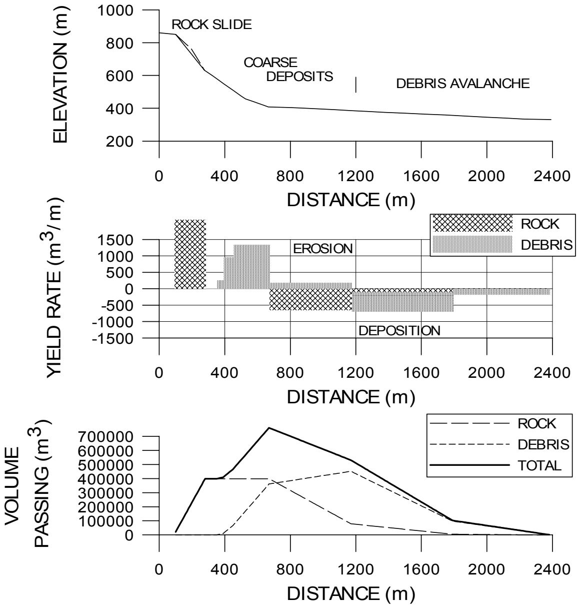
(Photos D.Ayotte)

Nomash River

Profile

Yield rate (m³/m)

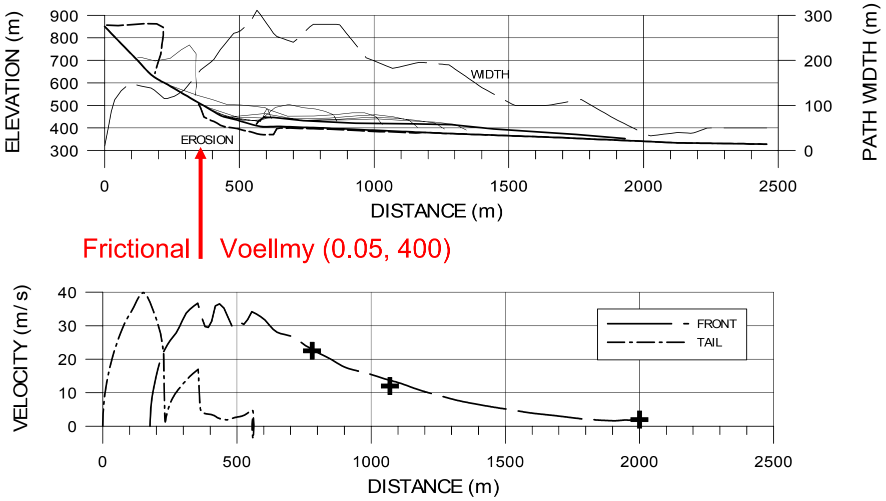
Volume balance



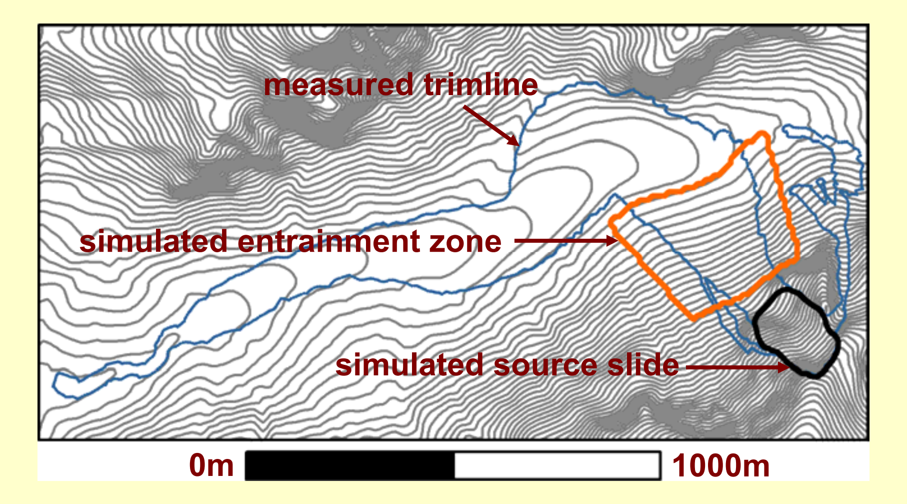
Model with material entrainment

Nomash River slide, 1999 (Hungr and Evans, 2004)

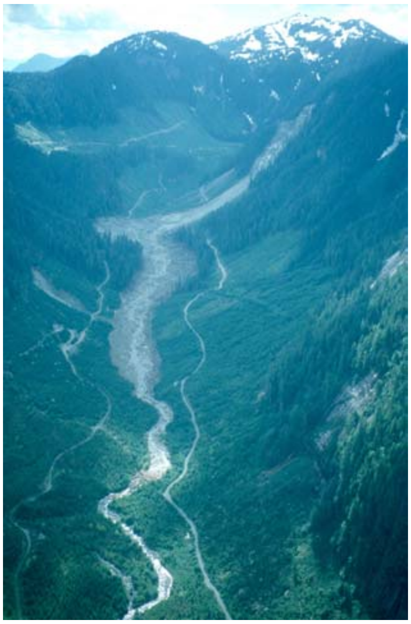
Source volume: 370 000 m³Entrained debris: 400 000 m³



Nomash River rock slide – debris avalanche



Nomash River rock slide – debris avalanche

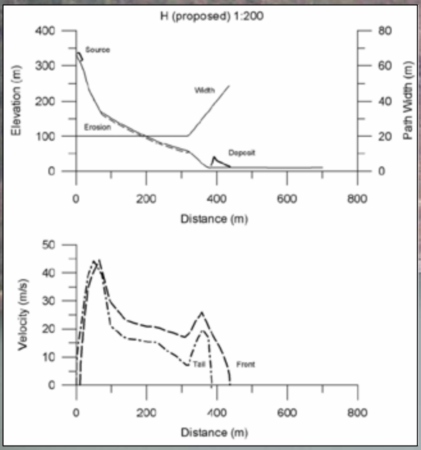


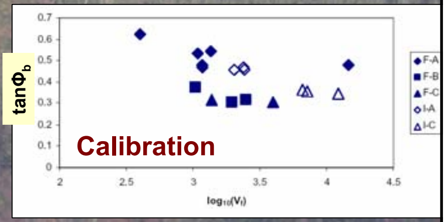
Simulation with entrainment

(McDougall and Hungr, 2005)

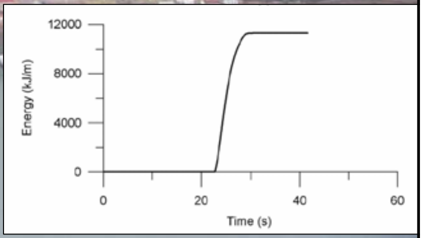
Real case, 2D analysis:

Real case: estimate flow energy at x=390 m





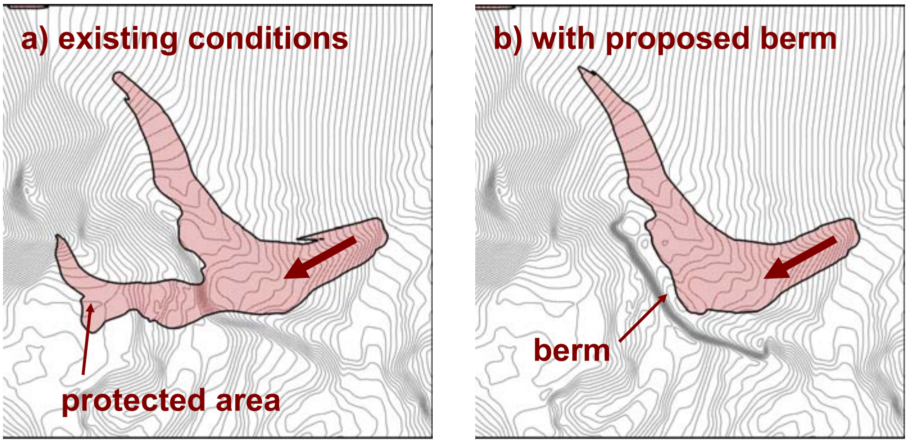
Calibration



Real case, 3D:

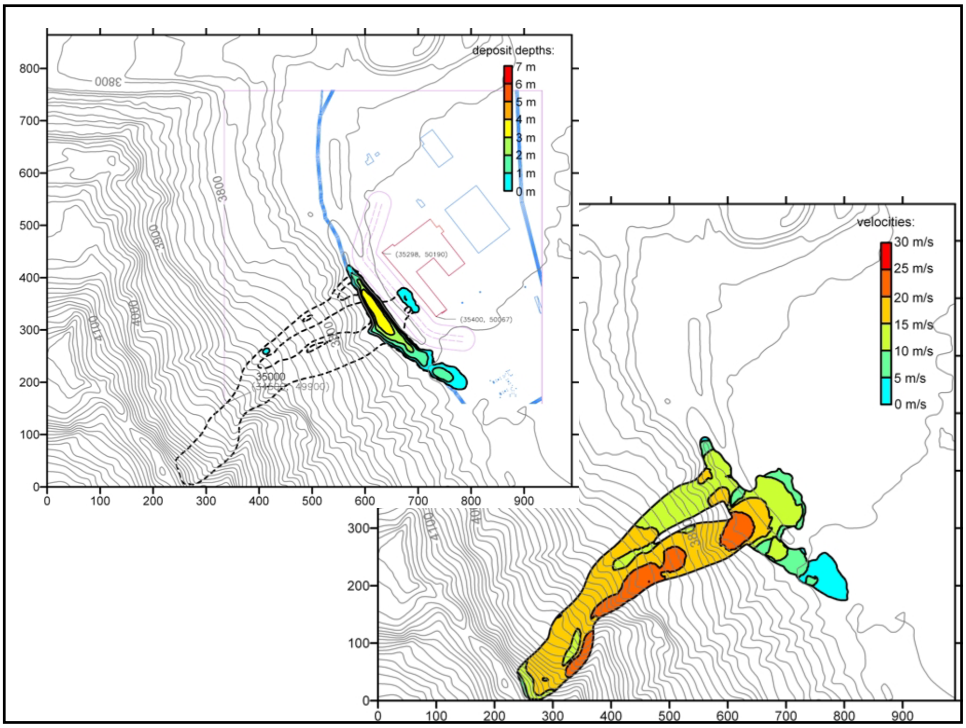
Real case, 3D:

1) influence of a proposed berm



- berm could potentially be effective

Another real case, Indonesia


deposit depths:
7 m
6 m
5 m
4 m
3 m
2 m
1 m
0 m
3800
3900
4000
4100
(35298, 50190)
(35400, 50067)
35000
(34500, 49900)
0
100
200
300
400
500
600
700
800
900
velocities:
30 m/s
25 m/s
20 m/s
15 m/s
10 m/s
5 m/s
0 m/s

Factory, Switzerland

Conclusions:

1. Landslides are complex, but predictions are possible
2. Our approach is to concentrate on the external aspects of behaviour. We consider the micro-mechanics intractable.
3. We should be open-minded about the rheological character of landslide motion
4. Analysis must consider the character of material forming the path
5. Material entrainment should be considered
6. Model verification and calibration are essential