Benchmarking Exercise on Landslide Runout Analysis

Provisional Review Findings

Report by
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International Forum on
Landslide Disaster Management 2007

Review Committee

- **Professor Oldrich Hungr**
  University of British Coulombia, Canada
- **Professor N R Morgenstern**
  University of Alberta, Canada
- **Ir H N Wong**
  Geotechnical Engineering Office, Hong Kong

International Forum on
Landslide Disaster Management 2007

Purpose

The Exercise is not a competition!

An opportunity to try out methods developed, compare the outcome and share experience/insight

- **to assess whether this emerging field of science is on its way towards establishing some degree of commonality amongst different methods/groups**
- **to take stock of progress made and issues to be further addressed**
- **to facilitate interaction among researchers and practitioners**

International Forum on Landslide Disaster Management 2007

Timetable

- 2006 - plan formulated; benchmarking cases identified and data compiled
- Mar/Apr 2007 - 22 teams invited; modelling packages issued
- Sep 2007 - results reports submitted by 13 teams from different countries
- Oct – Dec 2007 - review by Review Committee; assisted by a supporting team
- 12 Dec 2007 – presentation and discussion in 2007 Forum

International Forum on Landslide Disaster Management 2007

Data provided to participants :

1. DEM of downslope area (i.e. path and surrounding area)
2. DEM of landslide source
3. Descriptions of landslide, with data and photos
4. Plans of debris entrainment and deposition
5. Other relevant available information (e.g. velocity and duration)

Participants to contribute :

1. Brief description of model, theory and parameters adopted
2. Modelling results
3. Presentation and interaction in the 2007 Forum

Cases for Benchmarking

- **Group A - Validation cases**

  1 analytical solution, two laboratory tests
- **Group B – Typical Hong Kong landslides**

  Shum Wan; Fei Tsui Road; 1990 Tsing Shan debris flow; Sham Tseng San Tsuen debris flow
- **Group C - Large and unusal landslides**

  Frank slide (Canada); Thurwieser rock avalanche (Italy); 2000 Tsing Shan debris flow; Tate's Cairn debris flow (2005 + forward prediction); Lo Wan debris flood

Team	Model	Group A			Group B				Group C					
		Dam Break Sceaniro	Deflected Sand Flow	USGS Flume Test	Shum Wan Landslide	Fei Tsui Road Landslide	Tsing Shan Debris Flow 90	Sham Tseng San Tsuen Debris Flow	Frank Slide	Thurwieser Rock Avalanche	Tsing Shan Debris Flow 00	Tate's Cairn Landslide	Tate's Cairn Landslide Forward Prediction	Lo Wai Debris Flow
University of Alberta, Canada	Wang	●	●	●	●	●	●	●			●	●		●
University of Hong Kong	MADFLOW		●							●				
University of Milan, Italy	TOCHNOG	●			●				●	●				
NGI, Norway	RAMMS							●						
	DAN3D(NGI)							●				●	●	
	FLO-2D(NGI)											●		
Technical University of Catalonia, Spain	FLATMODEL	●		●			●				●	●	●	
GEO, Hong Kong	DMM	●	●	●	●	●	●	●	●	●	●	●	●	
Universite Paris Diderot, France	SHALTOP-2D	●		●	●	●			●					
	RASH3D(Paris)	●												
UBC, Vancouver, Canada	DAN	●	●			●	●		●					
	DAN3D				●	●	●	●		●		●	●	
CEDEX, Spain	Pastor	●	●	●	●	●	●	●	●	●	●	●	●	●
Vienna University of Technology, Austria	PFC								●	●				
Kyoto University, Japan	Sassa				●	●			●					
Politecnico Di Torino, Italy	RASH3D		●			●			●			●	●	
University at Buffalo, USA	TITAN2D		●						●					
	Number of submissions	7	7	5	7	7	5	5	9	6	4	7	6	2

Basic Concept - 1

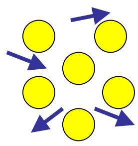
Fundamental Mechanics

Challenge:

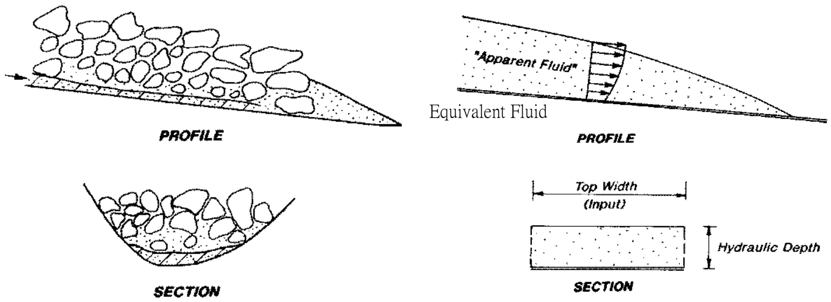
Mechanical behaviour of landslide materials and interfaces at extremely high deformation rates and displacements is to be modelled

Complications:

- **Heterogeneity and structure**
- **Non-linearity**
- **Scale dependence**
- **Rate dependence**
- **Sampling difficulties**
- **Complex solid/fluid interactions**
- **Time-dependent constitutive relationships**
- **Stress/strain path dependence**
- **… more?**



Basic Concept – 2
Concept of Equivalent Fluid



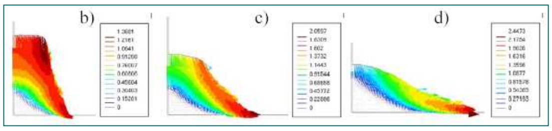
Prototype

Numerical Model Requires Calibration

Hungr (1995)

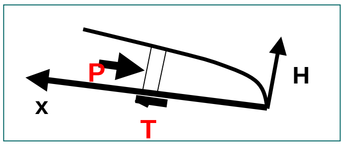
Solution Approaches

Differential
start from an element



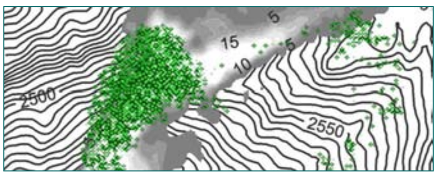
(Crosta et al.)

Integrated
start from a reference column



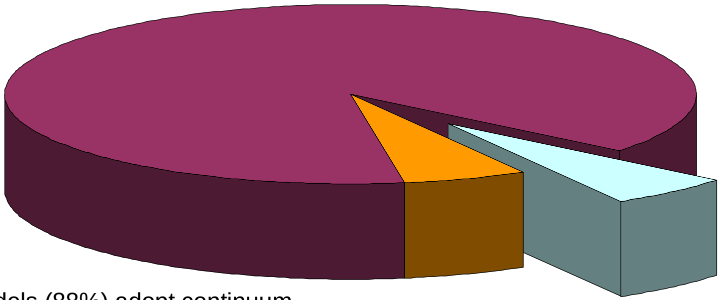
(Hungr et al.)

Particulate
discrete elements



(Poisel et al.)

Solution Approaches



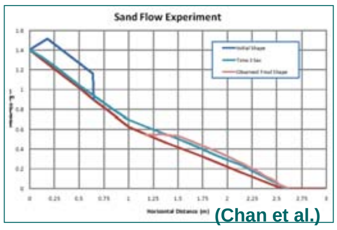
15 models (88%) adopt continuum assumption and integrated solution method (Wang, MADFLOW, RAMMS, DAN3D*(NGI), FLO-2D(NGI), FLATMODEL, DMM*, SHALTOP-2D, RASH3D(Paris), DAN, DAN3D*, Pastor*, Sassa, RASH3D & TITAN2D

* 4 models adopt smooth particle hydrodynamic or particle-in-cell approach

1 model (6%) adopts continuum assumption and differential solution (TOCHNOG)

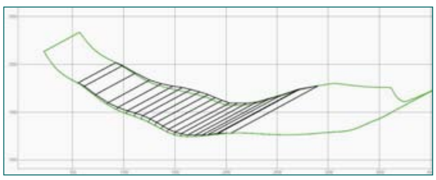
1 model (6%) adopts particulate assumption and discrete element solution (PFC)

Solution Dimensions



(Chan et al.)

2-D model
analysing cross-section only



Pseudo 3-D
analysing cross-section, but accounting for plan dimensions in the continuity equation

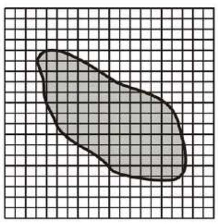
3-D
analysis in plan and cross-section

Solution Dimensions

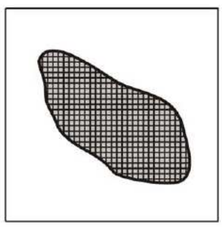
Team	Model	2D	Pseudo-3D	3D
University of Alberta, Canada	Wang	●		
University of Hong Kong	MADFLOW			●
University of Milan, Italy	TOCHNOG	●		●
NGI, Norway	RAMMS	●		●
	DAN3D(NGI)			●
	FLO-2D(NGI)			●
Technical University of Catalonia, Spain	FLATMODEL	●		●
GEO, Hong Kong	DMM	●		●
Universite Paris Diderot, France	SHALTOP-2D			●
	RASH3D(Paris)			●
UBC, Vancouver, Canada	DAN		●	
	DAN3D			●
CEDEX, Spain	Pastor			●
Vienna University of Technology, Austria	PFC	●		●
Kyoto University, Japan	Sassa			●
Politecnico Di Torino, Italy	RASH3D			●
University at Buffalo, USA	TITAN2D			●
	Total	6	1	15

Solution Reference Frame

Fixed (Eulerian)

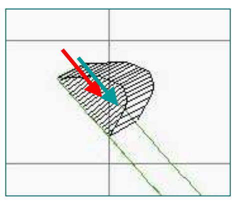


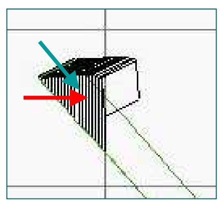
Moving (Lagrangian)



(McDougall, 2006)

The reference columns can be vertical or normal





Solution Reference Frame

Team	Model	Eulerian	Lagrangian	
			With Mesh	Mesh Free
University of Alberta, Canada	Wang		●	
University of Hong Kong	MADFLOW		● (adaptive)	
University of Milan, Italy	TOCHNOG	● (adaptive)	● (adaptive)	
NGI, Norway	RAMMS	●		
	DAN3D(NGI)			●
	FLO-2D(NGI)	●		
Technical University of Catalonia, Spain	FLATMODEL		●	
GEO, Hong Kong	DMM	●		
Universite Paris Diderot, France	SHALTOP-2D	●		
	RASH3D(Paris)	●		
UBC, Vancouver, Canada	DAN		●	
	DAN3D			●
CEDEX, Spain	Pastor			●
Vienna University of Technology, Austria	PFC			● (distinct element)
Kyoto University, Japan	Sassa	●		
Politecnico Di Torino, Italy	RASH3D	●		
University at Buffalo, USA	TITAN2D		● (adaptive)	
	Total	8	6	4

Basal Rheology

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

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

Where ϕ_b is the 'Bulk Friction Angle' (modified by pore pressure)

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

Pore-pressure modified rheology can be assumed frictional only if u is assumed linearly dependent on σ, regardless of stress level and velocity – modified by r_u as for slope stability calculations

Also: Pouliquen model: ϕ is depth-dependent?

Coupled sliding-consolidation model?

Basal Rheology

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

Frictional strength + turbulent effect

Plastic: $T = \tau$ Constant Yield strength

Viscous: $$T = \frac{3V\mu}{H}$$ Constant Viscosity

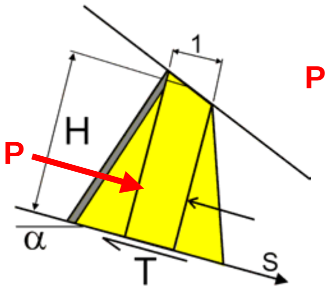
Bingham: Yield strength + viscous effect

Basal Rheology

Team	Model	Frictional	Voellmy	Three Term	Bingham	Others
University of Alberta, Canada	Wang	● (energy loss due to shear distortion)				
University of Hong Kong	MADFLOW	●	●		●	
University of Milan, Italy	TOCHNOG	● (elastoplastic)				
NGI, Norway	RAMMS	●	●			
	DAN3D(NGI)	●	●			
	FLO-2D(NGI)			●		
Technical University of Catalonia, Spain	FLATMODEL	●	●			
GEO, Hong Kong	DMM	●	●			
Universite Paris Diderot, France	SHALTOP-2D	●				Pouliquen friction
	RASH3D(Paris)	●	●	●		
UBC, Vancouver, Canada	DAN	●	●		●	
	DAN3D	●	●			
CEDEX, Spain	Pastor	● (consolidation)	● (consolidation)		● (consolidation)	Evolution function
Vienna University of Technology, Austria	PFC	●				
Kyoto University, Japan	Sassa	● (Δu)				
Politecnico Di Torino, Italy	RASH3D	●	●	●		Pouliquen friction
University of Buffalo, USA	TITAN2D	●				
	Total	**16**	**10**	**3**	**3**	**3**

Internal Stress and Energy Dissipation

(other than basal - integrated models only):



Pressure term: $P = \gamma k \dfrac{dH}{ds} H \cos\alpha$

k **– lateral earth pressure coefficient (unknown)**

Assumptions:

(1) Zero internal strength (Hydrostatic) k = 1

(2) "At Rest" condition constant k > 1

(3) Savage-Hutter formula

$$k_{(min/max)} = 2\left[\frac{1 \pm \sqrt{1-\cos^2\phi_i(1+\tan^2\phi_b)}}{\cos^2\phi_i}\right] - 1$$

(4) Rankine Equation

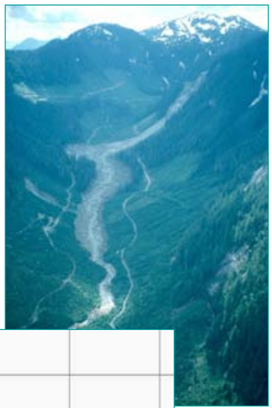
$$k = \frac{\pi}{4} \pm \frac{\phi}{2}$$

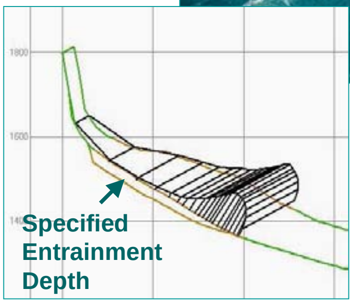
Internal Stress & Energy Dissipation Assumptions

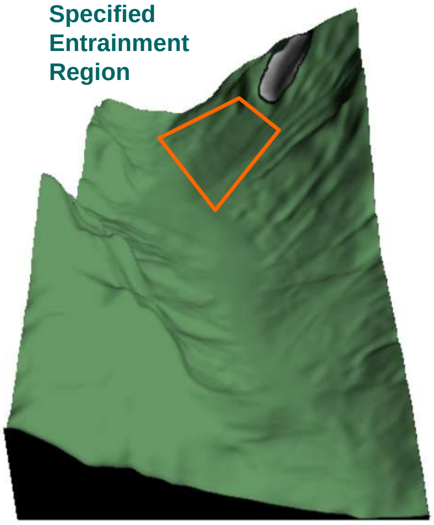
Team	Model	Hydrostatic	Rankine	At Rest	SH
University of Alberta, Canada	Wang		●		
University of Hong Kong	MADFLOW				●
University of Milan, Italy	TOCHNOG	N/A			
NGI, Norway	RAMMS	●			
	DAN3D(NGI)				●
	FLO-2D(NGI)	●			
Technical University of Catalonia, Spain	FLATMODEL	●			
GEO, Hong Kong	DMM				●
Universite Paris Diderot, France	SHALTOP-2D	●			
	RASH3D(Paris)				●
UBC, Vancouver, Canada	DAN				●
	DAN3D				●
CEDEX, Spain	Pastor				
Vienna University of Technology, Austria	PFC	N/A			
Kyoto University, Japan	Sassa			●	
Politecnico Di Torino, Italy	RASH3D				●
University of Buffalo, USA	TITAN2D				
	Total	**4**	**1**	**1**	**7**

SH – Savage-Hutter method

Entrainment of Material from Path







(McDougall and Hungr, 2005)

Entrainment of Material from Path

Team	Model	No	User	Algorithm
University of Alberta, Canada	Wang	●		
University of Hong Kong	MADFLOW		●	
University of Milan, Italy	TOCHNOG			●
NGI, Norway	RAMMS	●		
	DAN3D(NGI)		●	
	FLO-2D(NGI)	●		
Technical University of Catalonia, Spain	FLATMODEL			●
GEO, Hong Kong	DMM		●	
Universite Paris Diderot, France	SHALTOP-2D	●		
	RASH3D(Paris)		●	
UBC, Vancouver, Canada	DAN		●	
	DAN3D		●	
CEDEX, Spain	Pastor		●	
Vienna University of Technology, Austria	PFC	●		
Kyoto University, Japan	Sassa	●		
Politecnico Di Torino, Italy	RASH3D		●	
University of Buffalo, USA	TITAN2D	●		
	Total	7	8	2

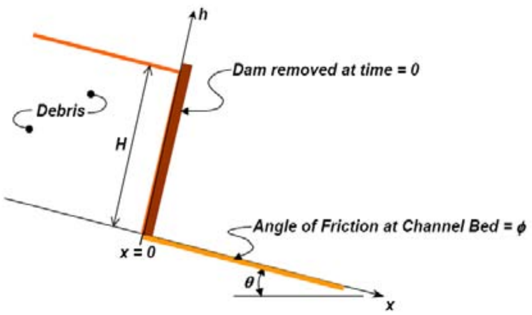
Variation of Basal Strength along Path

Team	Model	No	Yes
University of Alberta, Canada	Wang	●	
University of Hong Kong	MADFLOW	●	
University of Milan, Italy	TOCHNOG		●
NGI, Norway	RAMMS	●	
	DAN3D(NGI)		●
	FLO-2D(NGI)	●	
Technical University of Catalonia, Spain	FLATMODEL	●	
GEO, Hong Kong	DMM		●
Universite Paris Diderot, France	SHALTOP-2D	●	
	RASH3D(Paris)		●
UBC, Vancouver, Canada	DAN		●
	DAN3D		●
CEDEX, Spain	Pastor		●
Vienna University of Technology, Austria	PFC	●	
Kyoto University, Japan	Sassa		●
Politecnico Di Torino, Italy	RASH3D		●
University of Buffalo, USA	TITAN2D	●	
	Total	**8**	**9**

Group A

Validation Cases

Dam Break Scenario



Analytical Solution

$$h(t) = \begin{cases} H & ;\ x \le -x_R \\ \dfrac{1}{9g\cos\theta}\left(2c_o - \dfrac{x}{t} - \dfrac{1}{2}mt\right)^2 & ;\ -x_R < x < x_L \\ 0 & ;\ x_L \le x \end{cases}$$

where $x_R = c_o t + \frac{1}{2}mt^2$

$$x_L = 2c_o t - \frac{1}{2}mt^2$$

$$m = g(\cos\theta\tan\phi - \sin\theta)$$

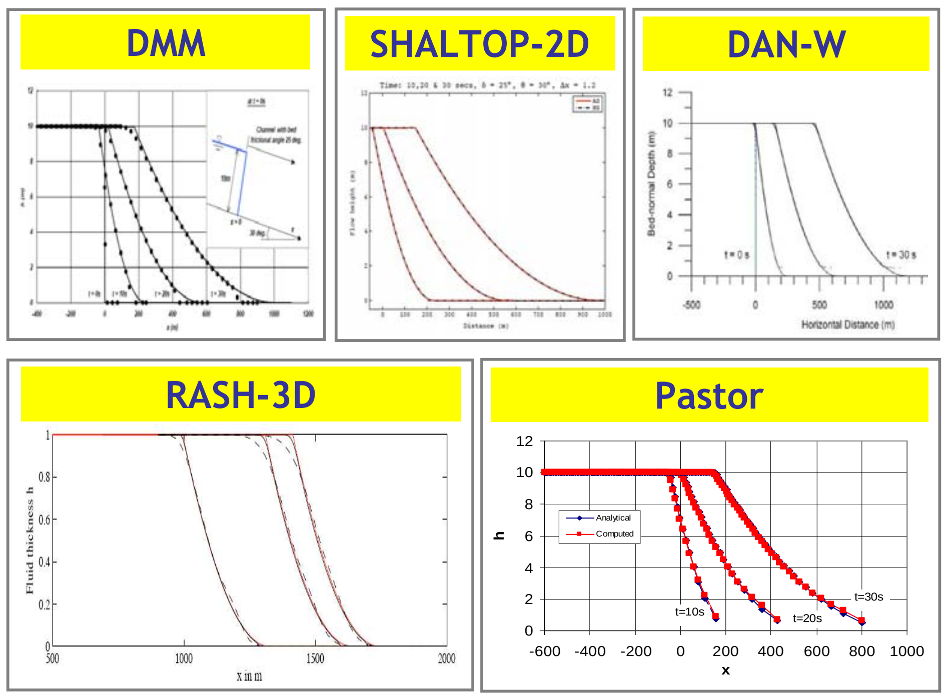
$$c_o = \sqrt{gH\cos\theta}$$

Model	
Wang	SHALTOP-2D
TOCHNOG	RASH3D
FLATMODEL	DAN
DMM	Pastor

H = 10 m

$\theta = 30°$

$\phi = 25°$



Observations

SHALLTOP-2D gives an excellent match

DMM and DAN3D show small mismatch at the distal end of debris

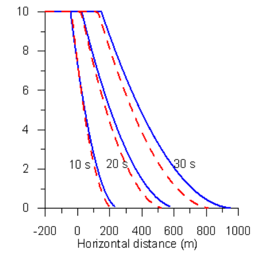
Pastor did not show results at distal end

RASH3D has minor deviation

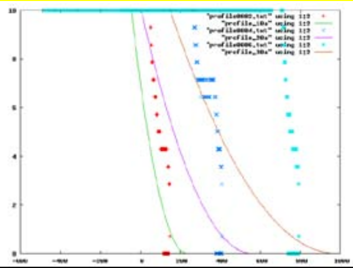
FLATMODEL matches the pattern but underestimation increases w/ time

TOCHNOG and Wang considered presence of internal strength – much short shorter runout

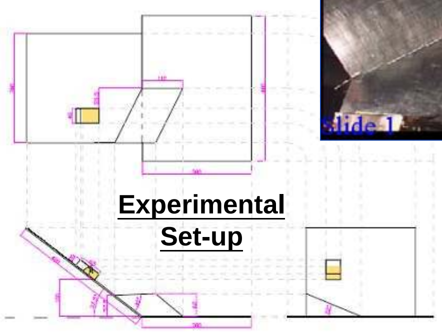
FLATMODEL



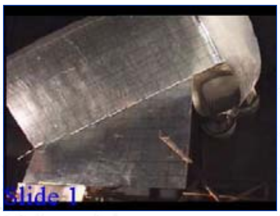
TOCHNOG



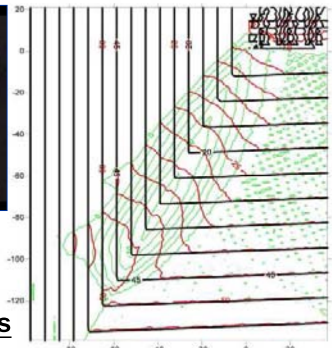
Deflected Sand Flow

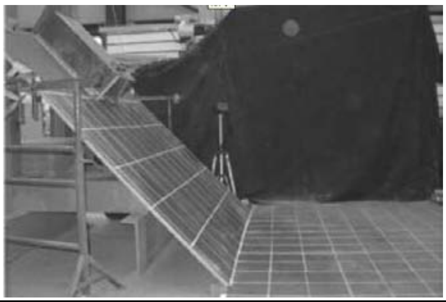


Experimental Set-up



Test Results





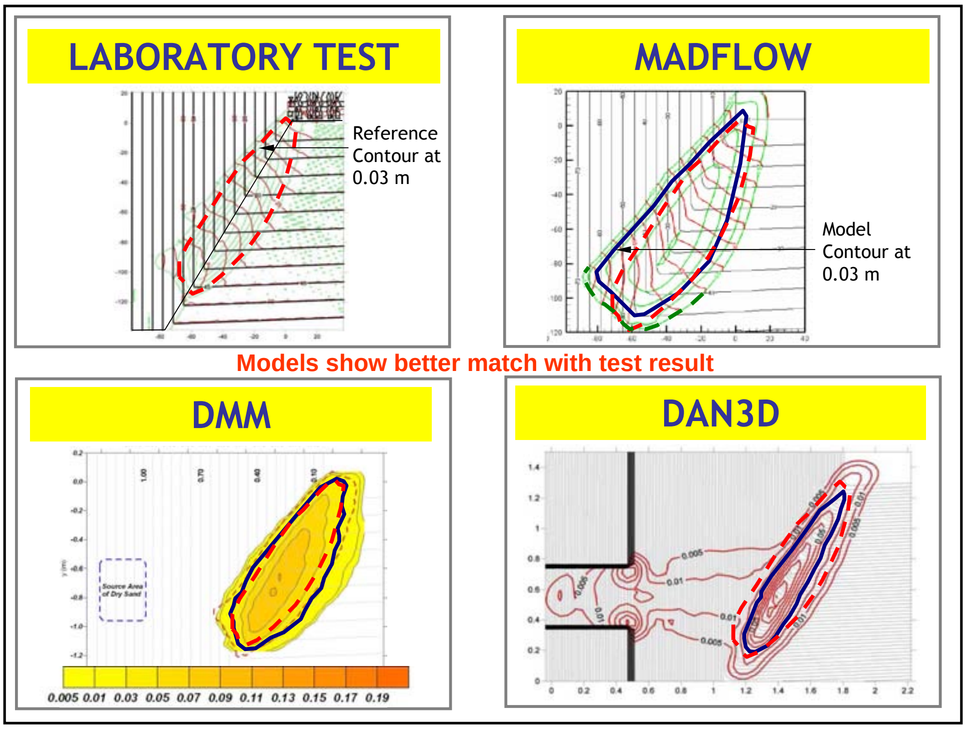
Volume = 30,000 cm^3 (0.03 m^3)

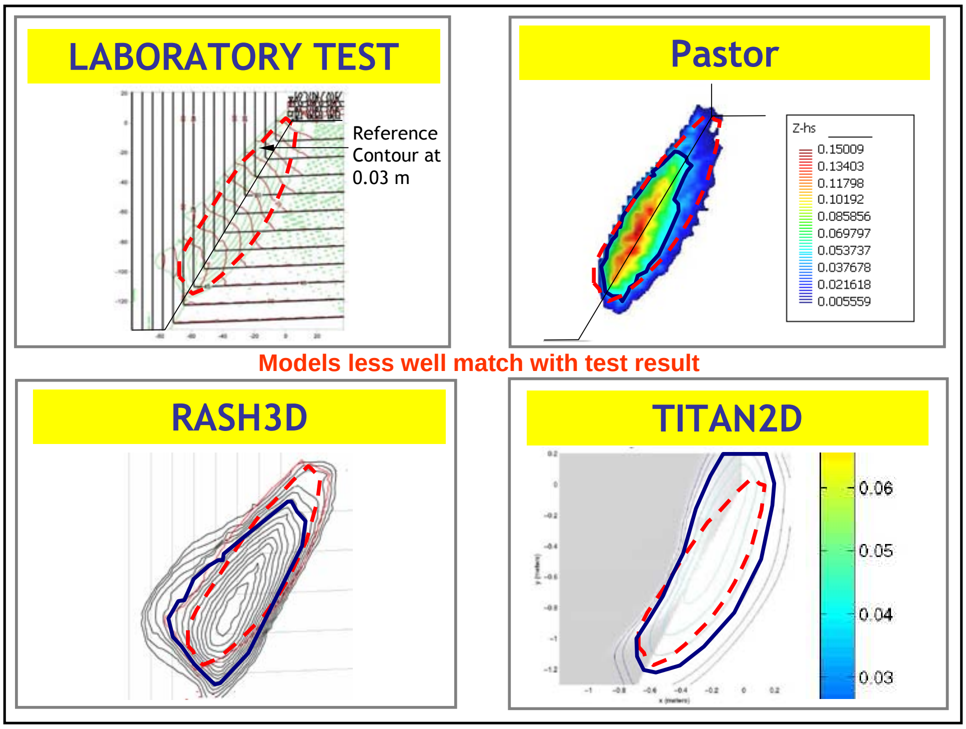
ϕ_{int} = 34°

ϕ_{bas} = 32°

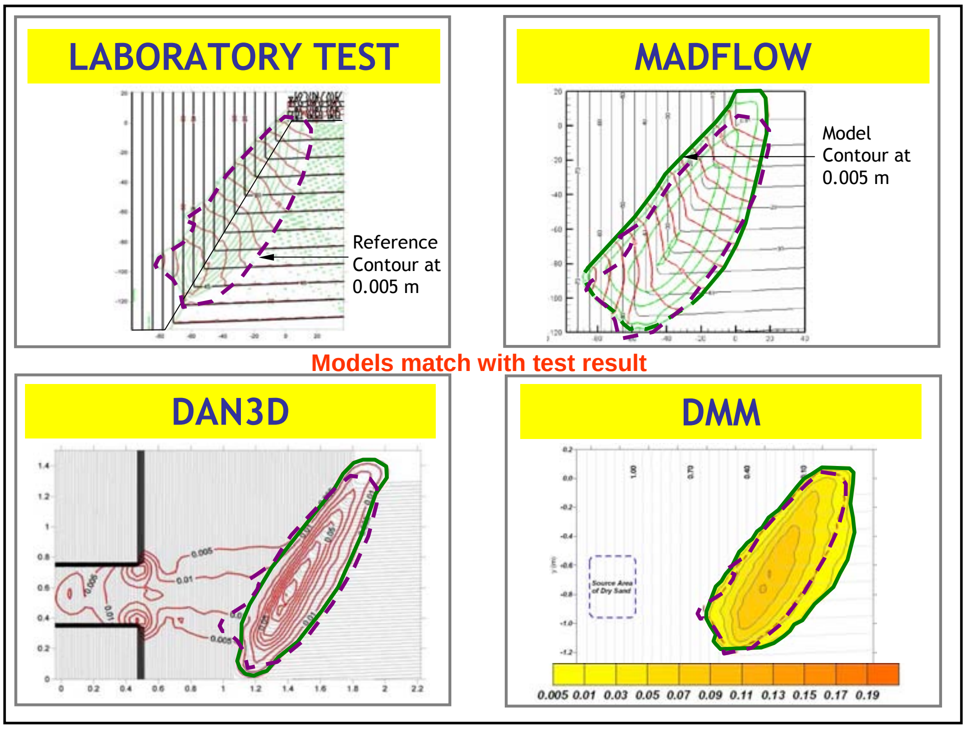
Model
Wang
MADFLOW
DMM
DAN3D
Pastor
RASH3D
TITAN2D

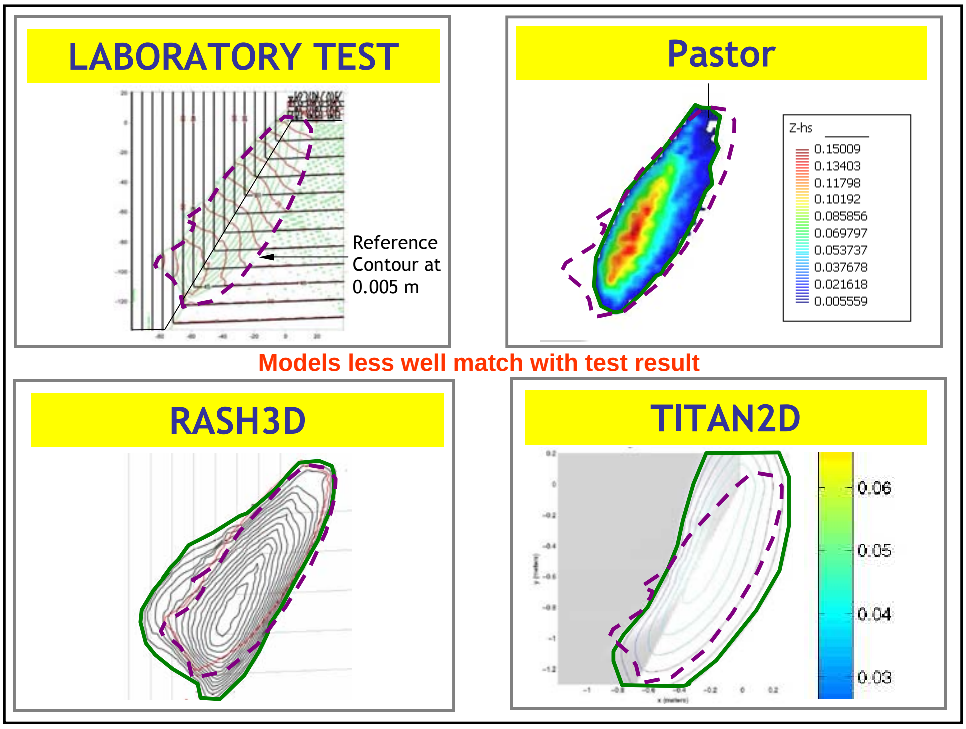
Deflected Sand Flow (showing 0.03 m contour)





Deflected Sand Flow (showing 0.005 m contour)


LABORATORY TEST
Reference Contour at 0.005 m
MADFLOW
Model Contour at 0.005 m
Models match with test result
DAN3D
DMM
0.005 0.01 0.03 0.05 0.07 0.09 0.11 0.13 0.15 0.17 0.19


LABORATORY TEST
Reference Contour at 0.005 m
Pastor
Z-hs
0.15009
0.13403
0.11798
0.10192
0.085856
0.069797
0.053737
0.037678
0.021618
0.005559
Models less well match with test result
RASH3D
TITAN2D
0.06
0.05
0.04
0.03

Observations

All six 3-D models have results resemble the test results in overall reach and shape of debris deposition

A better match with the test results not necessarily mean a better model, given the possible variations in material properties and test conditions

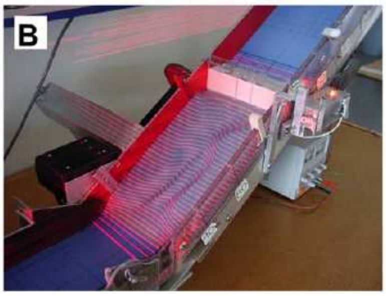
MADFLOW, DMM, DAN3D, RASH3D and Pastor tend to give consistent results, which also show a reasonable match with the experimental results

TITAN2D results show a much greater degree of spreading of the debris deposition

Variation in maximum deposition profiles may be related to different assumptions for internal stress distribution and modelling approaches

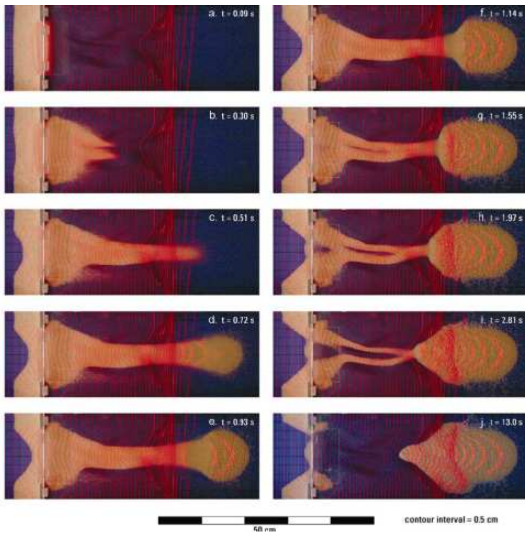
USGS Flume Test

Experimental Set-up



Model
Wang
FLATMODEL
DMM
SHALTOP-2D
Pastor

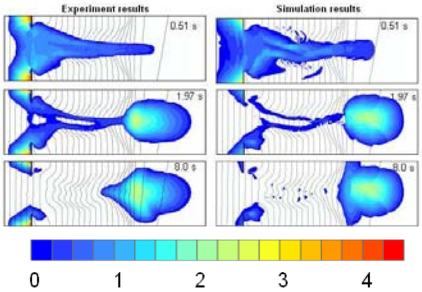
Test Results



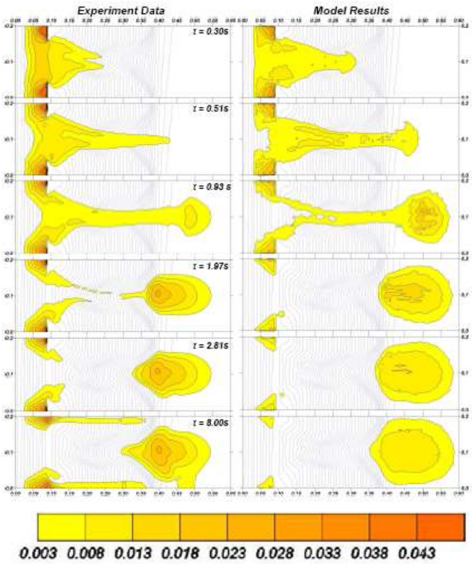
Volume = 308 cm^3 ϕ_{int} = 44°

ϕ_{bas} = 20° upper ϕ_{bas} = 23.5° lower

FLATMODEL

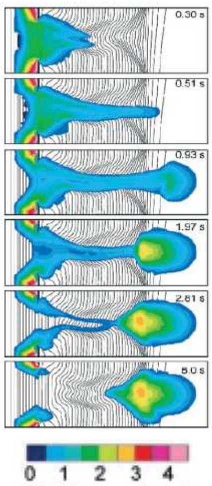


DMM

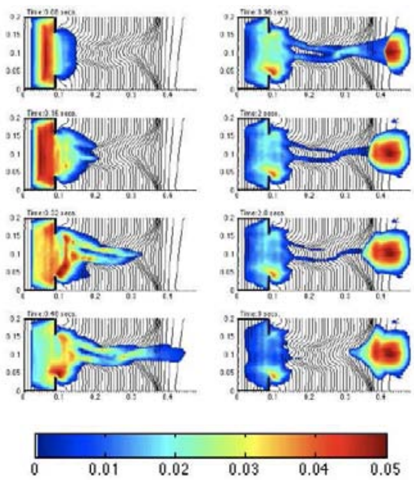


SHALTOP-2D

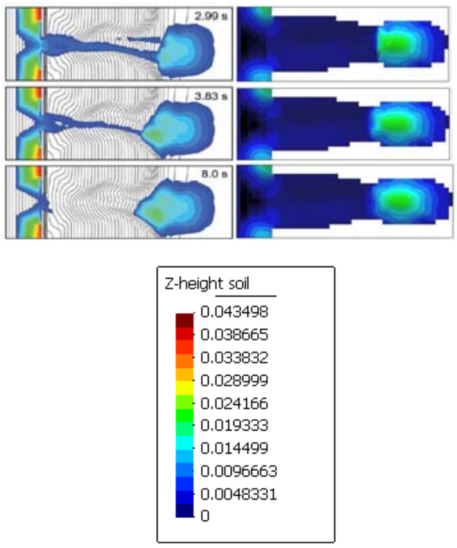
Experimental Result



Simulation Result



Pastor



Observations

All 4 models give results similar to test result

Apart from runout, good data on deposition, profile of material remains at source available for comparison

Results of FLATMODEL, DMM and SHALLTOP2D are consistent with test in debris runout and deposition

Results of Pastor are coarser than other models – affected by DEM?

As for deflected sand flow test, some variation in deposition profiles in different models, results of DMM and FLATMODEL more dispersed

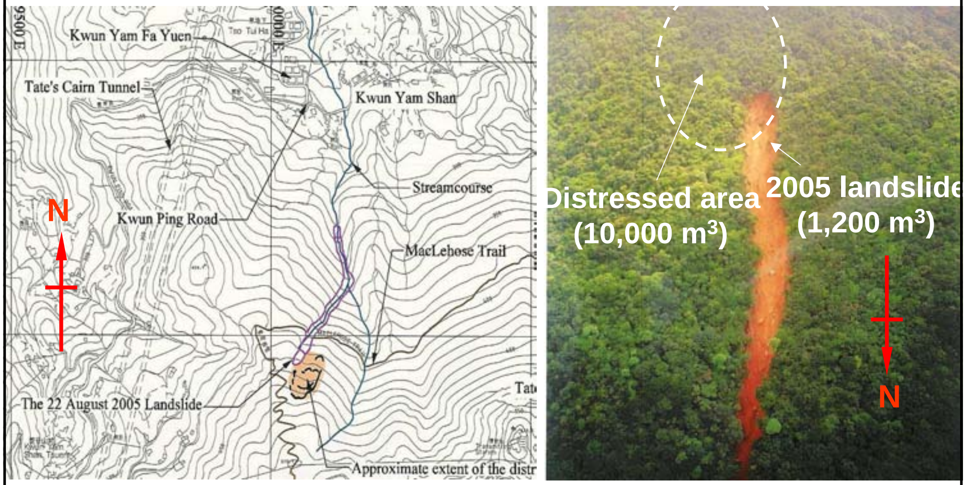
Groups B & C

Landslide Cases

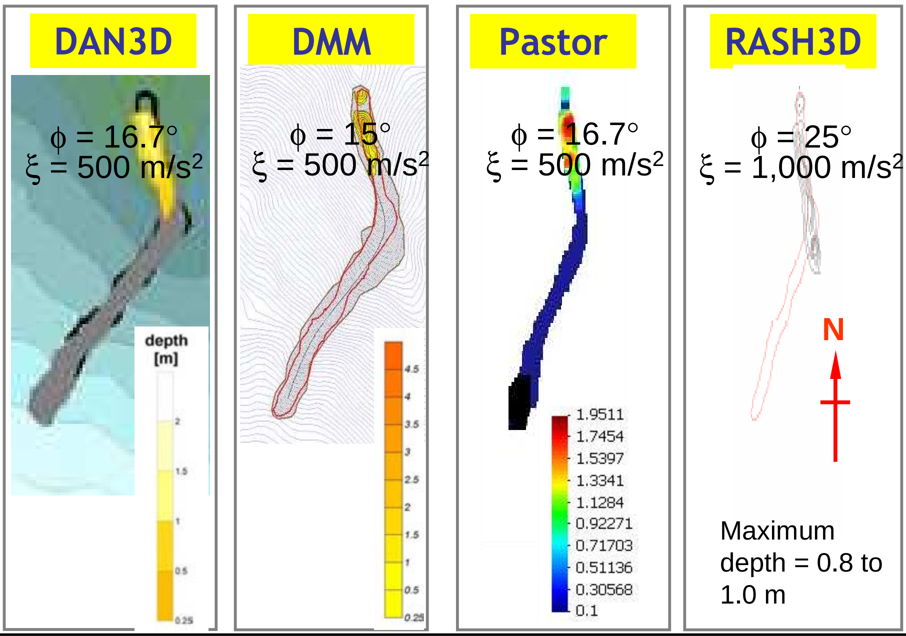
2005 Tate's Cairn Landslide

Back analysis of 2005 landslide (1,200 m^3) and forward prediction of 10,000 m^3 failure

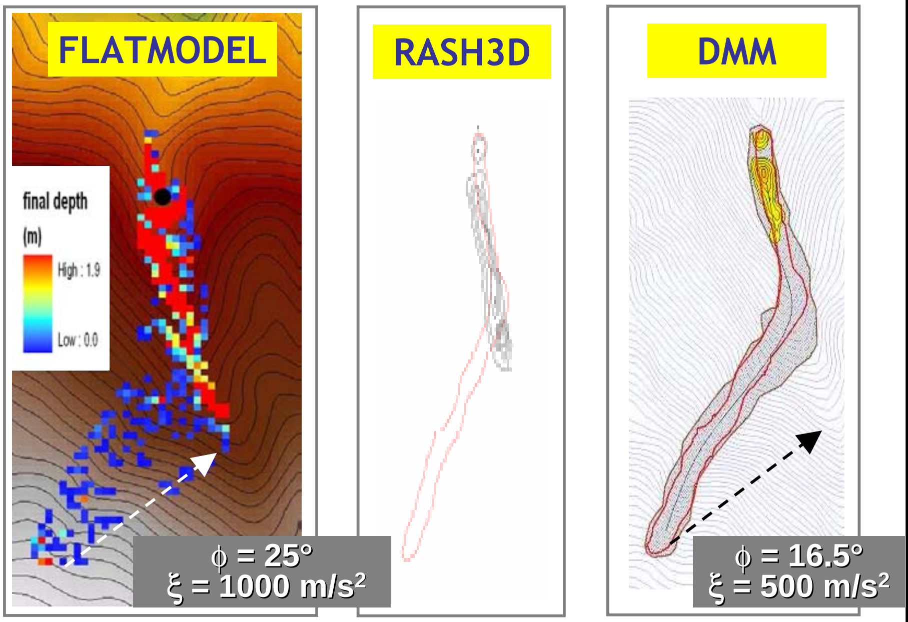
Debris flow path sensitive to source volume and geometry



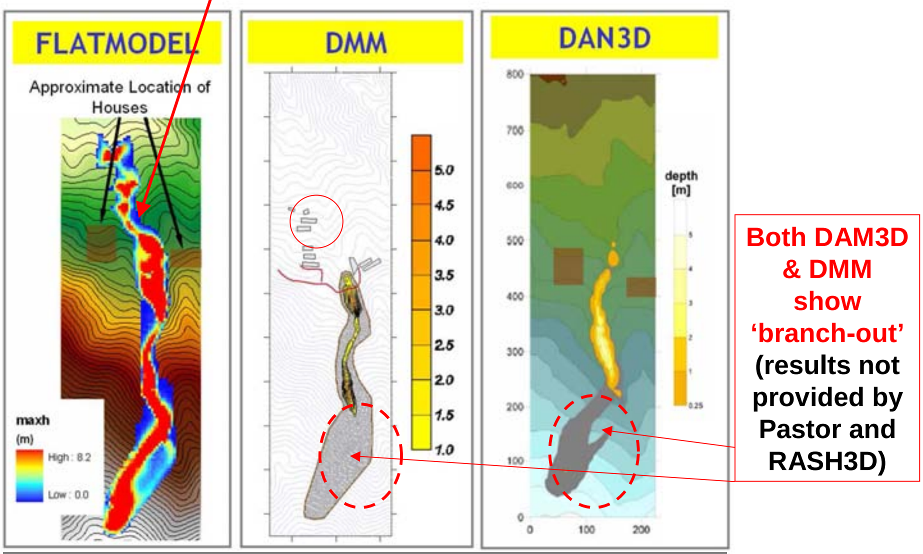
Consistent back-analysed results by different 3-D models using similar rheological parameters (1,200 m^3)



FLATMODEL gives different flow path (reasons not known)

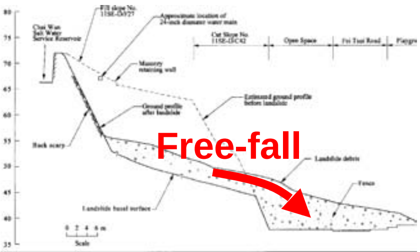


Debris apparently more mobile given same rheological parameters



Forward prediction using ϕ = 16.5°; ξ = 500 m/s²
(vol. = 10,000 m3; w/o entrainment)

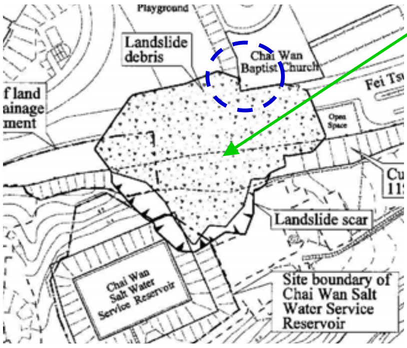
Fei Tsui Road Landslide



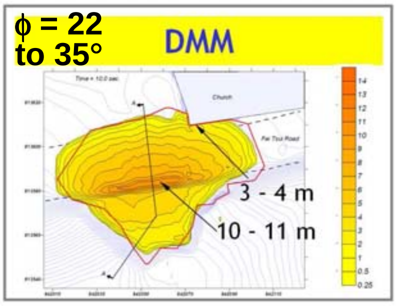
Open hillslope failure (14,000 m^3)

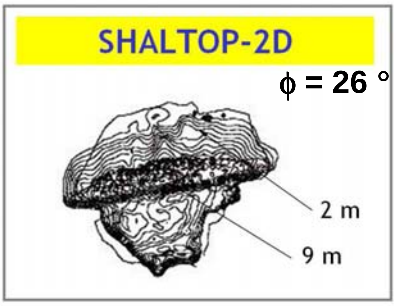
Debris partly obstructed by building

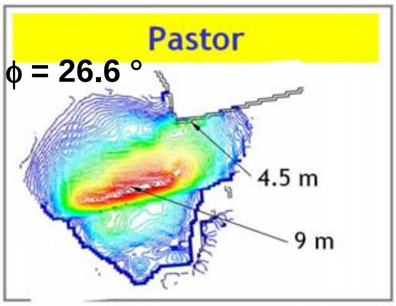
Possible free-fall and 3-D debris deposition profile (spreading)

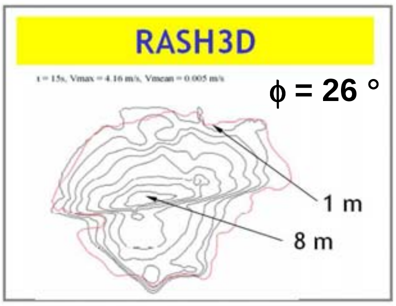


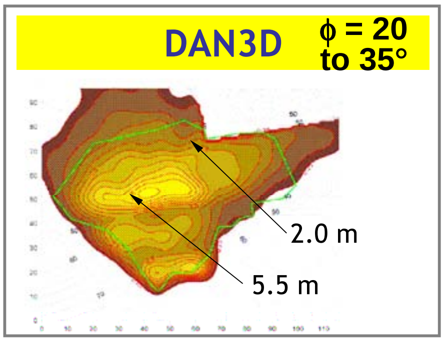
Models give consistent results, but with some discrepancy in deposition thickness



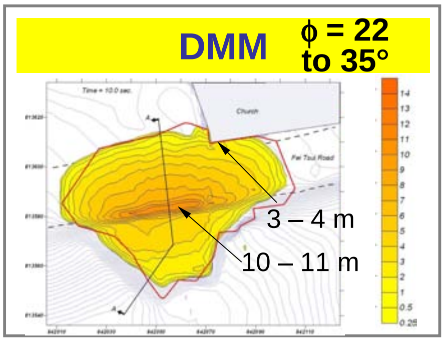


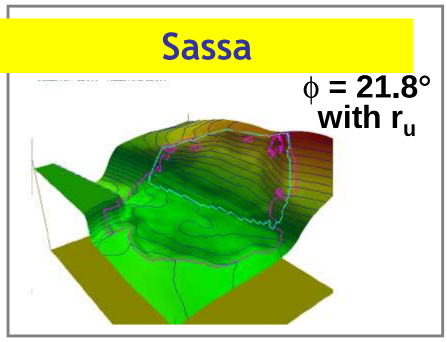






DAN3D gave more a disperse deposition zone, with smaller debris thickness



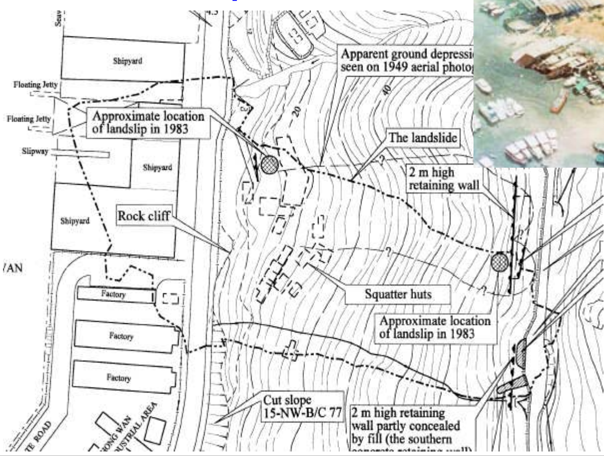


Detailed information on Sassa's simulated debris profile not available for direct comparison

Shum Wan Road Landslide

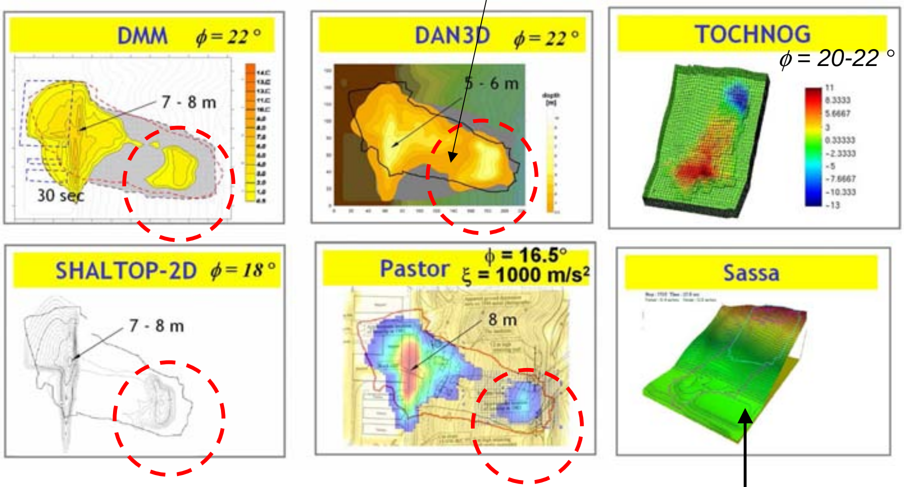
26,000 m^3 open hillside failure

3-D deposition profile with some debris remained on the landslide scarp



models give consistent results,
including deposition of debris on the landslide scarp

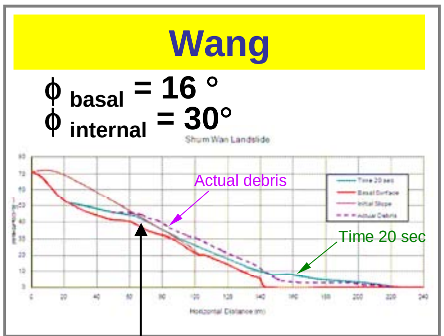
Debris not separated?



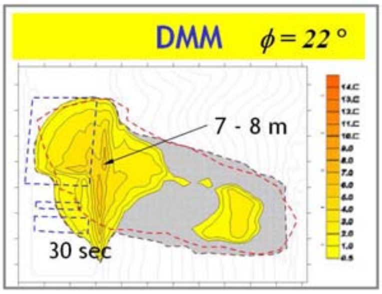
Details not available for direct comparison

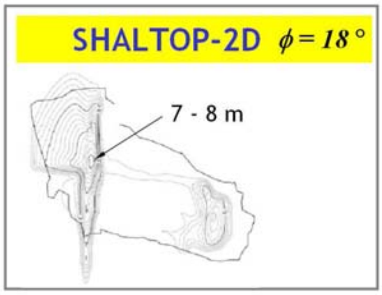
Comparison with Wang (UBC)'s Model

Consideration of energy loss due to internal shear distortion. Use of a lower basal ϕ gives similar mobility as Frictional Model

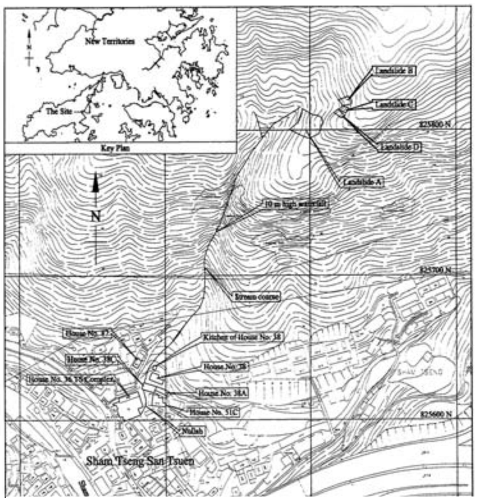


Continuum model without separation of debris





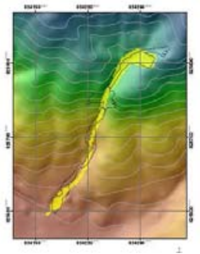
Sham Tseng San Tsuen Landslide



600 m^3 debris flow along incised drainage line

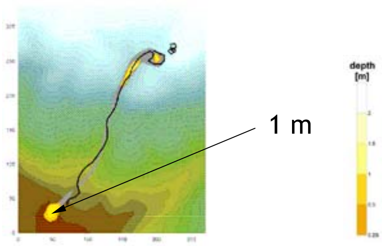
No entrainment involved

DAN3D(NGI) ϕ = 19.3°



Pastor ϕ = 20°

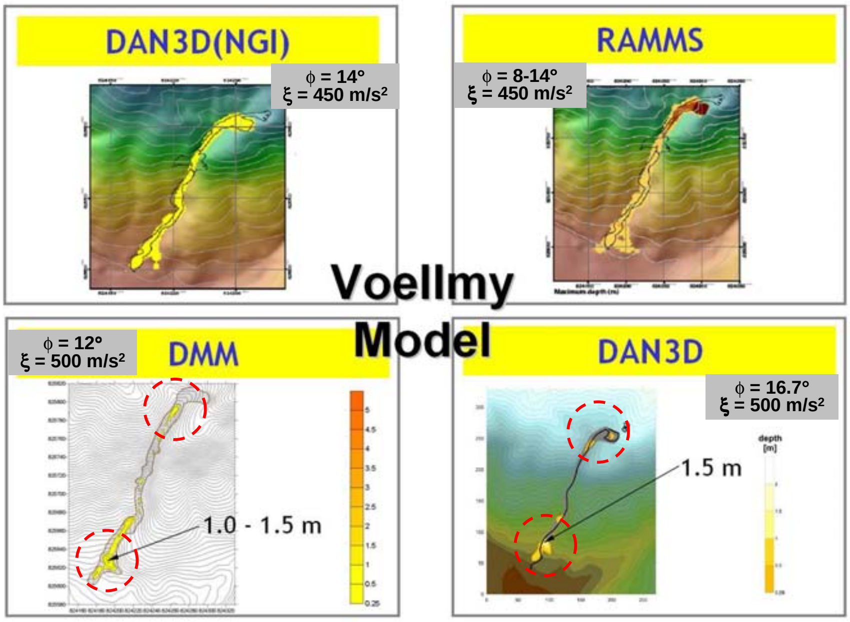
DAN3D ϕ = 17°

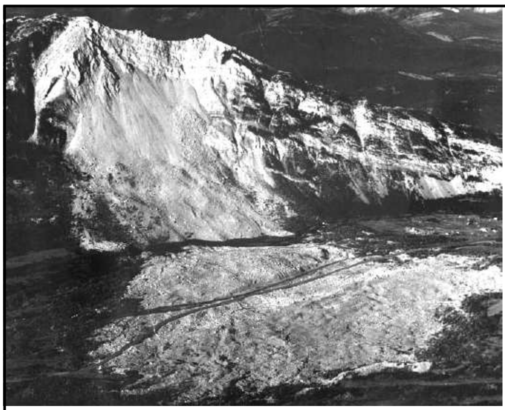


Frictional Model

Give consistent results, which resemble the landslide

Give consistent results, which resemble the debris flow (+ better match with velocity data)

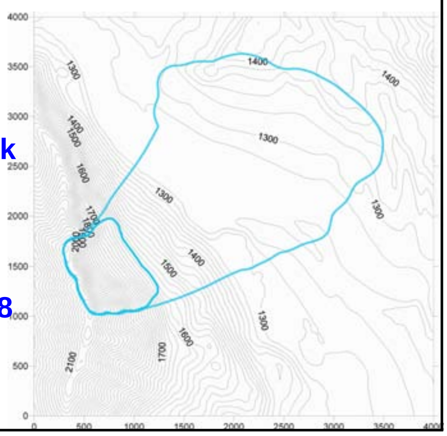




Frank Slide, Canada

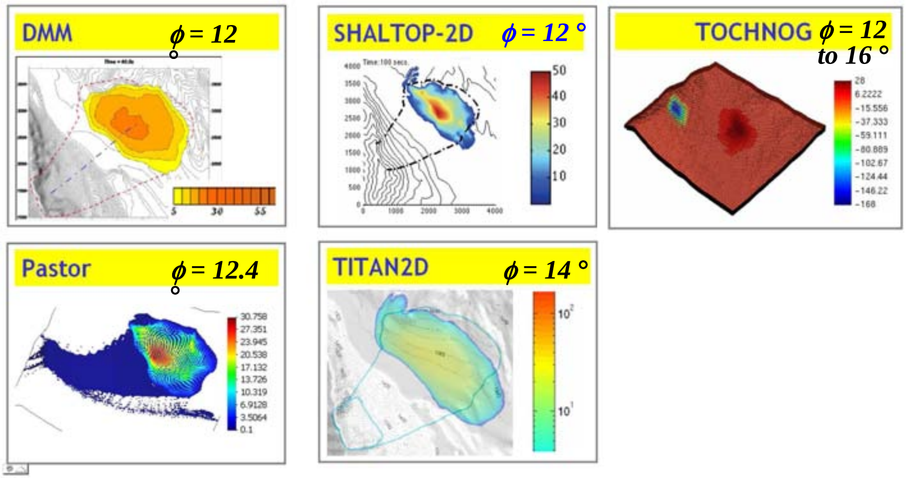
Occurred in 1903

Destroyed part of the town Frank, loss of 70 lives



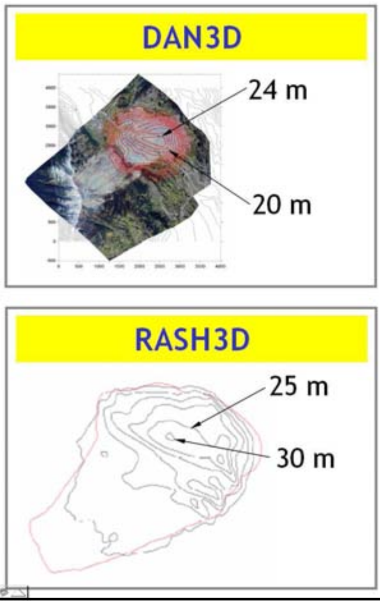
- **Large open hillslope (36 M m^3) rock avalanche, with debris runout to the opposite side of the valley**
- **Debris covers an area of 1.7 km wide x 2 km long, average depth 18 m**
- **Landslide lasted for < 100 sec**

DMM, SHALTOP-2D, Pastor and TITAN2D using frictional rheological model give similar results

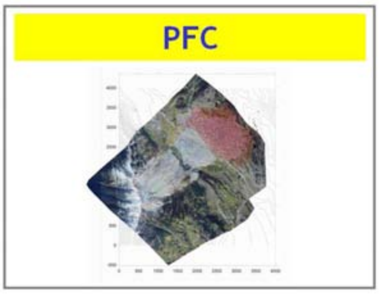


Runout modelled by Sassa; details not available for direct comparison.

DAN3D and RASH3D using similar Voellmy model give comparable results

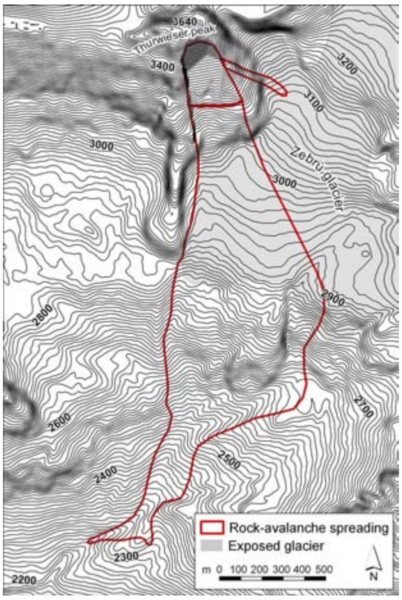


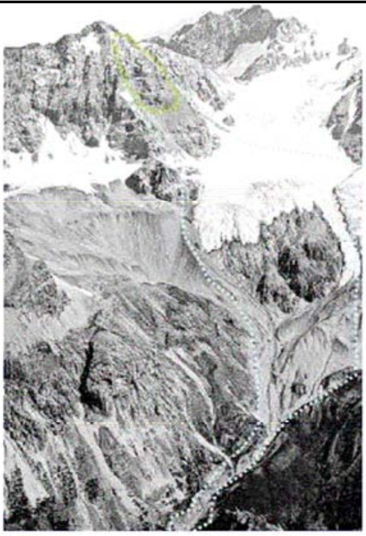
Runout geometry modelled by PFC. Direct comparison with other models is difficult.



Thurwieser Rock Avalanche

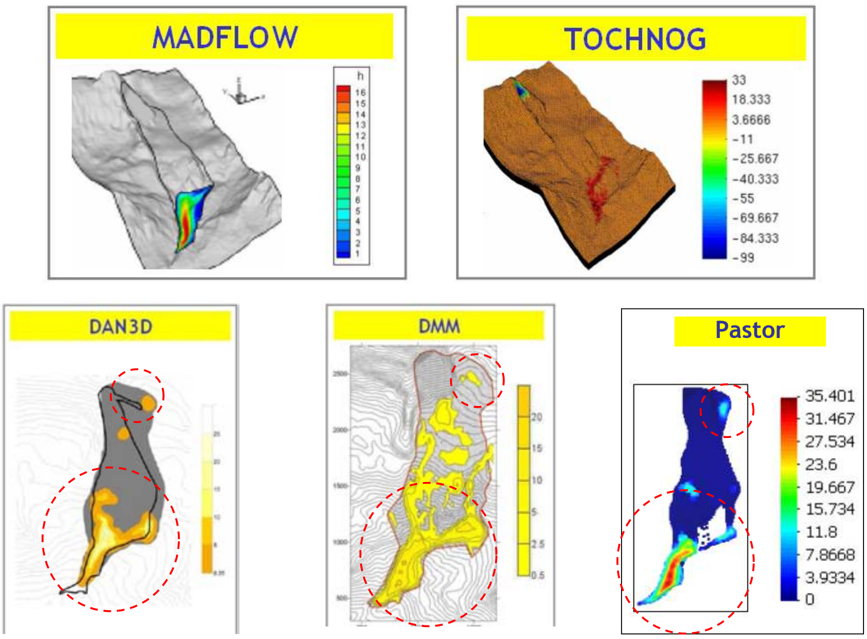
Occurred in 2004 in Punta Thurwieser, Central Italian Alps

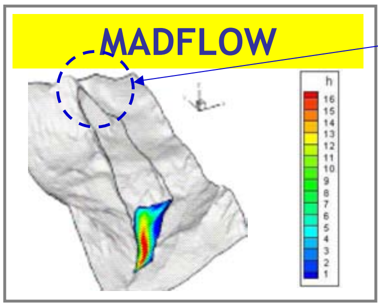




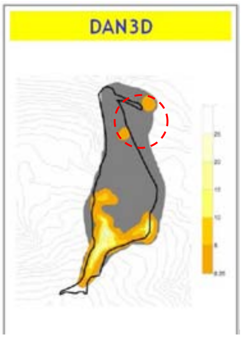
2.2 M m^3, irregular ground on runout trail covered by glacial ice, glacial deposit and rock exposures; landslide lasted < 75 - 80 sec

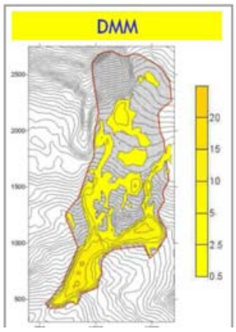
Give comparable results in respect of debris path and deposition

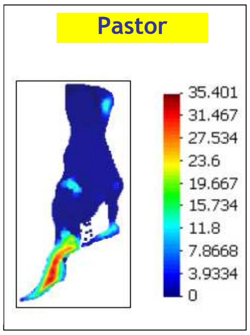




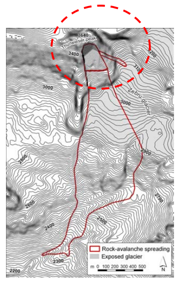
Without 'branch-out'
(not allowed for in
the modelling)





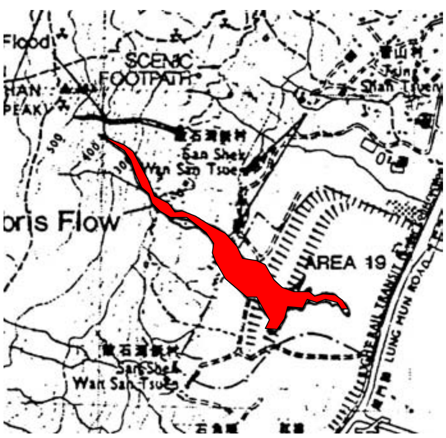


The landslide

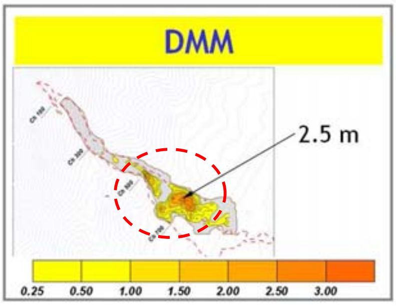


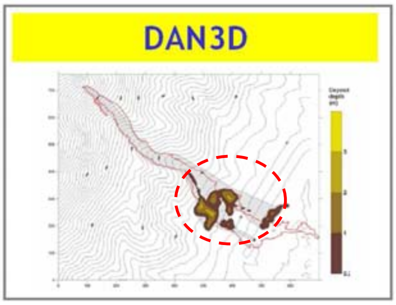
1990 Tsing Shan Debris Flow

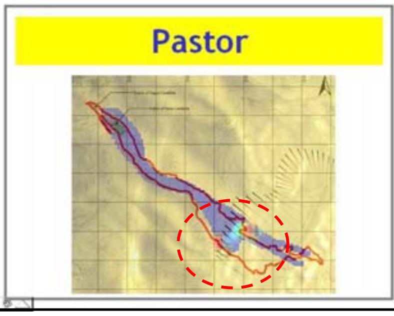
source volume 350 m³
significant entrainment giving final volume of 20,000 m³



Models show comparable results, but with different deposition profiles due to the different approaches in simulating entrainment





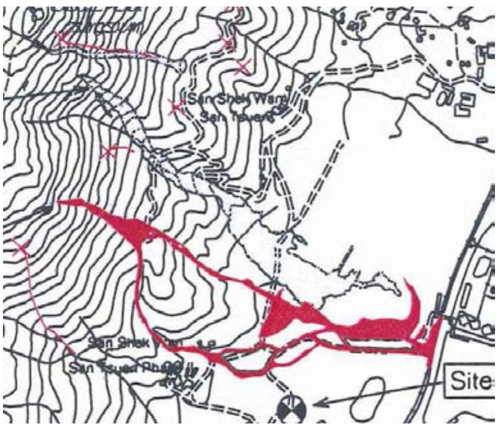


Model	Friction Angle ϕ (°)	Turbulent Coefficient ξ (m/s²)
Wang	Internal: 35 Basal: 24	-
FLATMODEL	11.3	$C_z = 8\ m^{1/2}/s$
DMM	15	500
DAN3D	11.3	500
Pastor	10.2	500

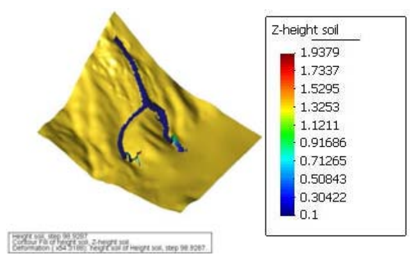
2000 Tsing Shan Debris Flow

Source volume 150 m^3; final volume 1,600 m^3

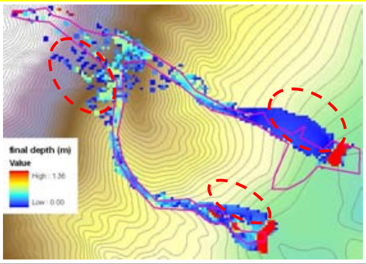
Debris trail bifurcated into two branches, requiring allowance for separation of debris in modelling



Pastor

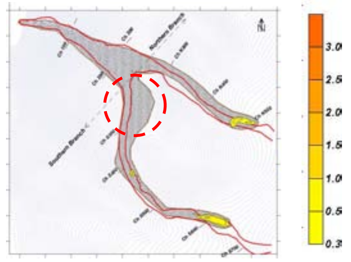


FLATMODEL



Pastor and DMM gave consistent results, which resemble the debris flow. FLATMODEL gave dispersed debris

DMM



Model	Friction Angle ϕ (°)	Turbulent Coefficient ξ (m/s²)
Wang	14	-
FLATMODEL	8.53	C_z = 20 $m^{1/2}/s$
DMM	Pylon Area: 45 Other Areas: 11	500
Pastor	10.2 (f=0.18)	500

Observations

DAN3D, DMM, Pastor and RASH3D with frictional and Voellmy basal rheology provided consistent modelling results.

SHALTOP2D with frictional rheology also gives consistent results.

Results of MADFLOW, TOCHNOG, RAMMS and TITAN2D are available in only a small number of cases.

Discrepancies in profile of the debris deposition zones may be related to internal stress assumptions.

Results of FLATMODEL appear to show greater difference c.f. others. Insufficient details from Sassa for direct comparison.

PFC, Wang & FLO-2D provide different rheological consideration. Results not directly compared.

(Note: Giving similar results not necessarily means 'better')

Observations

Consistency in results from different models is encouraging.

3-D model is useful in simulating the source, runout flow path and deposition zone, which are 3-D in geometry.

Ability to model separation and merging of debris along the runout path is required in dealing with more complicated cases.

Provision for entrainment is less well developed. The modes of entrainment assumed affect simulation results.

The runout models not suited for simulating the stability condition at source (e.g. extent and geometry of failure/ detachment).

No provision for change in DEM after debris deposition.

Application of Debris Mobility Modelling

(a) Selection of methods of analysis for different problems

3-D models preferred

Allow for debris entrainment

Allow for splitting (and merging) of debris

Models with the use of solution method, rheology and material parameters are relevant to (and representative of) the actual situation being analysed

Typical landslides and debris flows simulated by Voellmy and frictional basal rheology

Debris flows that involve watery debris will need Bingham or other rheological models that better simulate the hydraulic aspects

Rock falls simulated using discrete element method for particulate interaction

Application of Debris Mobility Modelling

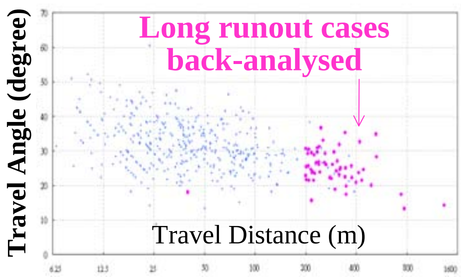
(b) Selection of rheological parameters

Back-analysis - consider nature of the landslide, materials involved, the debris runout and deposition, and other data (e.g. entrainment, field data on debris velocity)

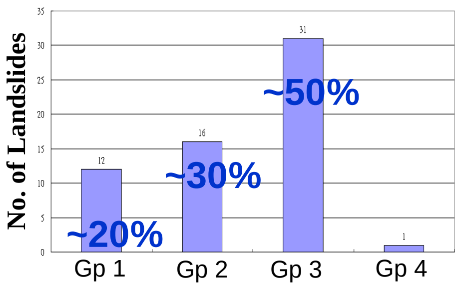
Forward prediction - back-analysing a large number of relevant historical landslide cases provides an indication of the likely range of rheological parameters.

Alternatively, use of suitably conservative rheological parameters in scenario-based analysis and design

Back-analysis of Probabilistic Distribution of Mobility



Historical Runout Data



Cases back-analysed

Increasing mobility

Gp	ϕ (deg)	ξ (m/s^2)	Prob.
1	8	500	~20%
	11	500	
2	15	1,000	~30%
	20	5,000	
3	20	1,000	~50%
	25	1,000	
4	30	5,000	Small

Probabilistic Distribution for Long Runout Cases

Application of Debris Mobility Modelling

(c) Modelling of debris flow path and lateral influence zone

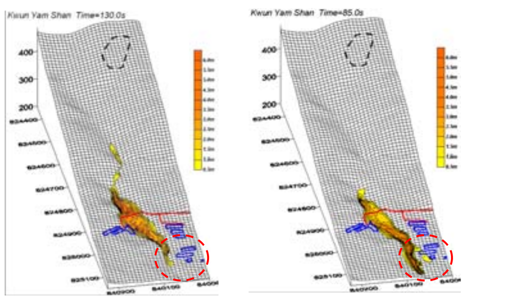
Debris runout path is affected by the DEM, which is a simplified representation of the actual ground topography

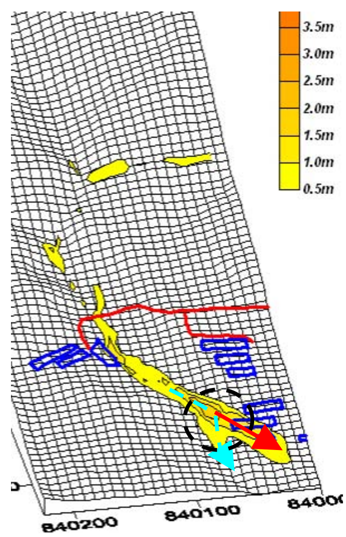
Debris may not necessarily travel along the steepest path of the DEM as in the case of a standard GIS 'rain-drop' analysis

Splitting/bifurcation of debris may occur

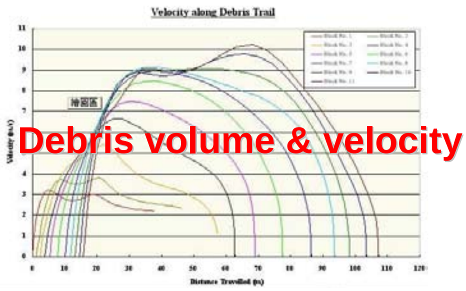
DEM and is typically unchanged during the debris runout process but accumulation of debris at a drainage line may change the debris flow path

Debris may fill up low point, leading to change in debris flow path





Interaction between debris and barrier



Application of Debris Mobility Modelling

(d) Debris impact and interaction with barriers

The current models have little provision for simulating the interaction between the debris and the structures

It is difficult to reliably interpret and determine the debris impact force or energy, for use in design of debris barriers

Acknowledgement:

Provisional review findings by the Review Committee, results reports provided by participants, slides given by Oldrich Hungr, support provided by the supporting team (Julian Kwan, Florence Ko and Thomas Wong) in preparation of the case packages and review of the submissions are gratefully acknowledged

Thank You

International Forum on
Landslide Disaster Management 2007