Design Event for Natural Terrain Hazards

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NTHS Overall Approach

HAZARD REVIEW (Stage 1):
Does a Hazard Exist?

ASSESSMENT (Stages 2 & 3):
What is the Hazard?
Where is it?
Can it Happen Again?
How Big is it?
What will it affect &
Possibility of First Time Failures?

MITIGATION STRATEGY (Stage 4):
What is the Best Way of Mitigating the Hazard?

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Design Event

- Generally a Qualitative Assessment Approach
- Mobility / Proximity Assessment
- Landslide Size and Susceptibility
- Consequence Consideration
- Uncertainty Built in and Conservatism Often Applied
- Good Engineering Geological & Geomorphological assessment required to determine appropriate volumes and potential for :

CONSERVATIVE EVENTS = 1:100 year

WORST CREDIBLE EVENTS = 1:1000 year

LOW FREQUENCY / HIGH MAGNITUDE EVENTS > 1:1000 ?? year

Design Event

- Historical landslide record (NTLI, ENTLI, LLS, Boulder Field, Additional API, Field Mapping).
- Interpreted Engineering Geological / Geomorphological Setting.
- Hazard Model for Open Hillslope Landslides, Channelised Debris Flows, Deep-seated Slides, Rock Fall & Boulder Fall.
- Predicted landslide source volumes and run-out characteristics (interpreted through debris flow modelling back analysis of historical landslides wherever possible)

Aerial Photograph Interpretation

Key Elements for the Design Event Estimates

- Identification of landslide history
  - Landslide Inventories of location / size / volume / run-out etc.
  - Comparison with GEO Report No 138 tables
  - Landslide frequency and susceptibility
- Initial interpretation of regolith types
  - Soil Morphographical Maps
- Determine geomorphology of Study Area
  - Morphological Maps
  - Hazard Maps
- Run-out models and assess landslide mobility
- Consequence model

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Field Mapping

Key Elements for the Design Event Estimates

- Confirm observations made during the API
- Confirmation of Landslides, Hazards and Models
- Regolith Mapping
  - Soil types and distribution
  - Thickness estimates
- Channel Mapping
  - Channel Morphology
  - Channelisation Ratio
  - Entrainable Material Estimates
- Identification of Hillslope Distress
  - Tension cracks
- Consequence model confirmation

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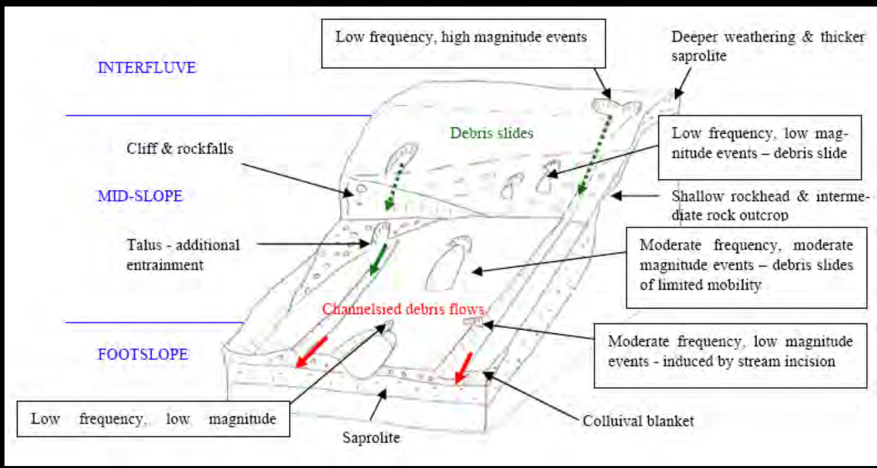
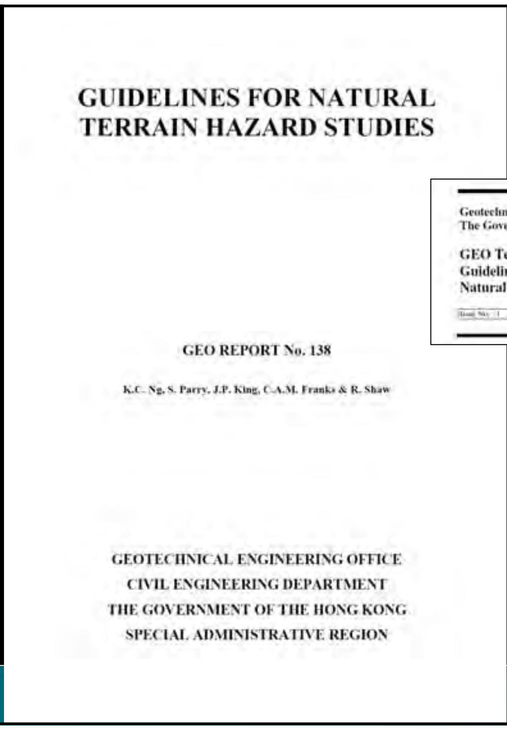
Development of the Hazard Model



Schematic Hazard Model (after Parry & Ng, 2007)

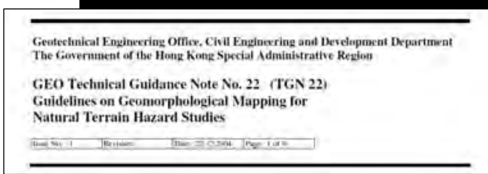


GUIDELINES FOR NATURAL TERRAIN HAZARD STUDIES

GEO REPORT No. 138

K.C. Ng, S. Parry, J.P. King, C.A.M. Franks & R. Shaw

GEOTECHNICAL ENGINEERING OFFICE
CIVIL ENGINEERING DEPARTMENT
THE GOVERNMENT OF THE HONG KONG
SPECIAL ADMINISTRATIVE REGION



Geotechnical Engineering Office, Civil Engineering and Development Department
The Government of the Hong Kong Special Administrative Region

GEO Technical Guidance Note No. 22 (TGN 22)
Guidelines on Geomorphological Mapping for
Natural Terrain Hazard Studies

- Supplemented with TGN 22 and various other GEO Reports

Facility Types

- Site Inspection
- Existing Facility Types for LPMit
- LPMit should be Group 1 or 2 ONLY ?

Table 1 - Grouping of Facilities (adapted from Wong, 1998)

Group No.	Facilities
1	(a) Buildings - any residential building, commercial office, store and shop, hotel, factory, school, power station, ambulance depot, market, hospital/polyclinic/ clinic, welfare centre
	(b) Others - bus shelter, railway platform and other sheltered public waiting area - cottage, licensed and squatter area - dangerous goods storage site (e.g. petrol station) - road with very heavy vehicular or pedestrian traffic density
2	(a) Buildings - built-up area (e.g. indoor car park, building within barracks, abattoir, incinerator, indoor games' sport hall, sewage treatment plant, refuse transfer station, church, temple, monastery, civic centre, manned substation)
	(b) Others - road with heavy vehicular or pedestrian traffic density - major infrastructure facility (e.g. railway, tramway, flyover, subway, tunnel portal, service reservoir)
3	- densely-used open space and public waiting area (e.g. densely-used playground, open car park, densely-used sitting out area, horticultural garden) - quarry - road with moderate vehicular or pedestrian traffic density
4	- lightly-used open-air recreation area (e.g. district open space, lightly-used playground, cemetery, columbarium) - non-dangerous goods storage site - road with low vehicular or pedestrian traffic density
5	- remote area (e.g. country park, undeveloped green belt, abandoned quarry) - road with very low vehicular or pedestrian traffic density
Note:	For roads, the Facility Group should be based on Figure A13 (Wong, 1998) taking into account the actual Annual Average Daily Traffic and the number of road lanes. For footpaths alongside roads, it may be assumed that footpaths are within the same group as the adjoining roads, except for Expressways (EX), Urban Trunk Roads (UT) and Rural Trunk Roads (RT). Footpaths alongside EX, UT and RT roads may be taken, by default, as a Group 5 facility, unless dictated otherwise by site-specific conditions.

Susceptibility Classes

- API Record
- Field Mapping
- Relict features
- Geological / Geomorphological control
- Similar nearby terrain
- Judgement

Table 4 - Susceptibility Classes

Susceptibility Class	Description
A	The natural terrain is extremely susceptible to the type of failure under consideration, with a notional annual probability of occurrence in the order of 1/10 or higher. For example: there are signs of instability, continued movement, or records of repeated recent failures (say over the past 50 to 100 years as observed from aerial photographs) in the catchment and its relevant vicinity.
B	The natural terrain is highly susceptible to the type of failure under consideration, with a notional annual probability of occurrence within the order of 1/10 to 1/100. For example: there are records of occasional recent failures in the catchment and its relevant vicinity.
C	The natural terrain is moderately susceptible to the type of failure under consideration, with a notional annual probability of occurrence within the order of 1/100 to 1/1000. For example: there are few records of recent failures, but there are indications of relict failures, or geomorphological evidence of potential problems in the catchment and its relevant vicinity, or any other evidence from similar terrain in Hong Kong.
D	The natural terrain is of low susceptibility to the type of failure under consideration, with a notional annual probability of occurrence less than 1/1000. For example: there are no records of recent and relict failures, little geomorphological and other evidence of potential problems in the catchment and its relevant vicinity, and little other evidence from similar terrain in Hong Kong.
Note:	In assessing the susceptibility of the hillside to failure, consideration should be taken of the potential effects of changes in environmental factors, e.g. any changes to the overall setting of the terrain such as hill fires and construction upslope, and the relevance of the available historical landslide records. Most of the information on environmental changes can be obtained from a review of past aerial photographs.

Consequence Classes

- Proximity run-out model
- Cross-sections
- LPMit should have identified these correctly

Table 3 - Consequence Classes

Proximity	Facility Group	
	1 & 2	3
Very Close (e.g. if angular elevation from the site is ≥ 30°)	I	II
Moderately Close (e.g. if angular elevation from the site is ≥ 25°)	II	III
Far (e.g. if angular elevation from the site is < 25°)	III	IV

Notes:
(1) Facility groups are given in Table 1. Facilities of Groups 4 and 5 normally do not require natural terrain hazard study and hence they are not included in Table 3.
(2) For channelized debris flow, if the worst credible event affecting the site is judged to have a volume exceeding 2000 m^3, the angular elevation given in the above examples should be reduced by 5°.
(3) The examples given above are for general guidance only. Other factors, such as credible debris path, topographical conditions and site-specific historical data, should also be taken into account in assessing the "proximity" of the natural terrain to the site.
(4) This Table is applicable only to sites that require natural terrain hazard study.

Design Requirements

Table 2 - Design Requirements for the Design Event Appr

Susceptibility Class (see Table 4)	Consequence Class (see Table 3)		
	I	II	III
A	WCE	WCE	WCE
B	WCE	WCE	CE
C	WCE	CE	CE
D	N	N	N

N

Notes:
(1) The recommended minimum design requirements are given in this Table. The designer may adopt a more conservative design or provision of other precautionary/warning measures if considered necessary.
(2) This Table will be applied to each sub-catchment and normally the predominant type of hazard will control the design requirements.
(3) WCE = Adopt a "worst credible event" as the design event.
CE = Adopt a "conservative event" as the design event
N = Further study is not required

Catchment	Facility Type	Facility Group	Consequence Class	Susceptibility Class (Max)	Design Requirement
NTHS A	Primary Helipad	2(b)	II	B	WCE
	Guard House	2(a)	III	B	CE
	Laydown Area	5	II	B	WCE
NTHS B	LP Vent / Pipeline	2(b)	II	B	WCE
NTHS C	Access Road	2(b)	III	C	CE
	LNG Pipeline	2(b)	II	C	CE
NTHS D	Access Road	2(b)	III	D	N
	LNG Pipeline	2(b)	III	D	N

CE = 1:100 year landslide from API record

WCE = Notional 1:1000 year landslide from Geomorphology and Relict Features

Catchment	Facility Type	Potential Hazard Type	Design Requirement	Design Event Magnitude
NTHS A	Primary Helipad Guard House Laydown Area	Rock Fall (Toppling)	WCE	All overhanging blocks
NTHS B	LP Vent / Pipeline	Open Hillslope Landslide Boulder Fall	CE CE	35m^3 5m^3
NTHS C	Access Road LNG Pipeline	Boulder Fall	CE	20m^3

Landslide Data

- Grouped into the various Landslide Types
  - Open Hillslope
  - Channelised Debris Flow
  - Deep Seated
  - Boulder Fall
  - Rockfall
- How large ?
- How mobile, Travel Angle, Travel Distance ?
- API and Field Mapping usually provides this data
- Landslide Volume and Frequency

GEO Report No 138 – Design Event

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Magnitude Cumulative Frequency Curves

- More suited to larger regional / area study with lots of landslides
- Site specific due to differences in geomorphology, terrain and geology
- Errors can occur dependent on the completeness of the Historical Landslide data set

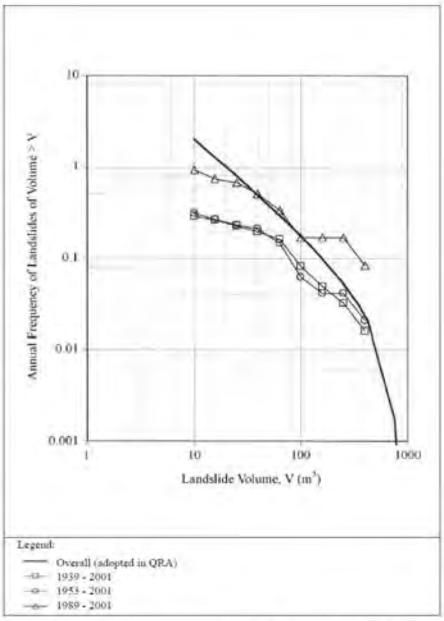

Figure 5.22 - Volume-Frequency Distribution for Landslides at Pat Heung (OAP, 2003)

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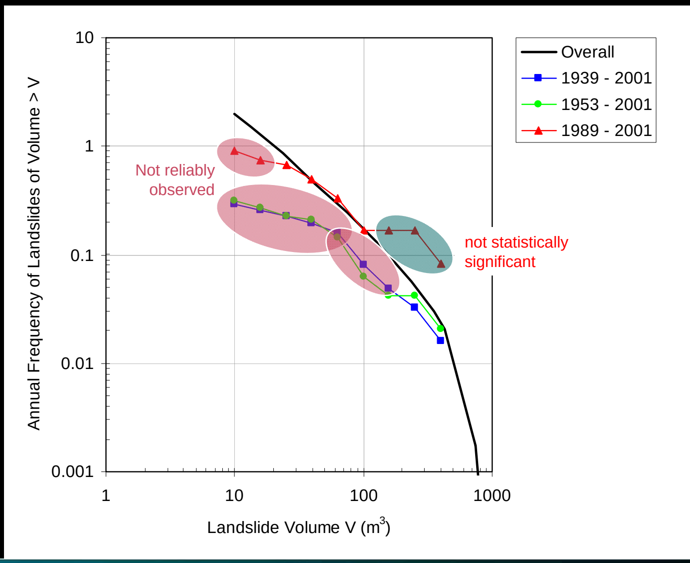
Magnitude Cumulative Frequency Analysis – Problems



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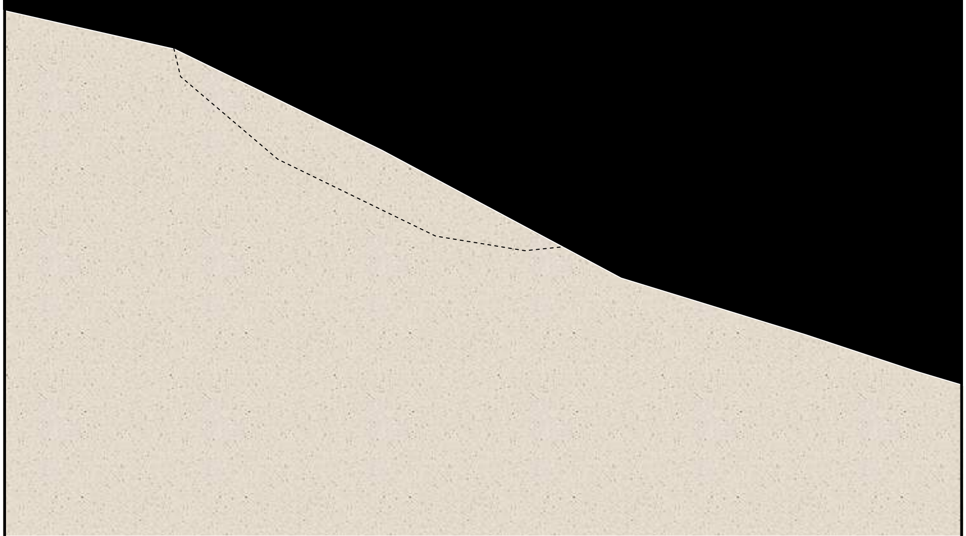
Landslide Debris Travel Distance



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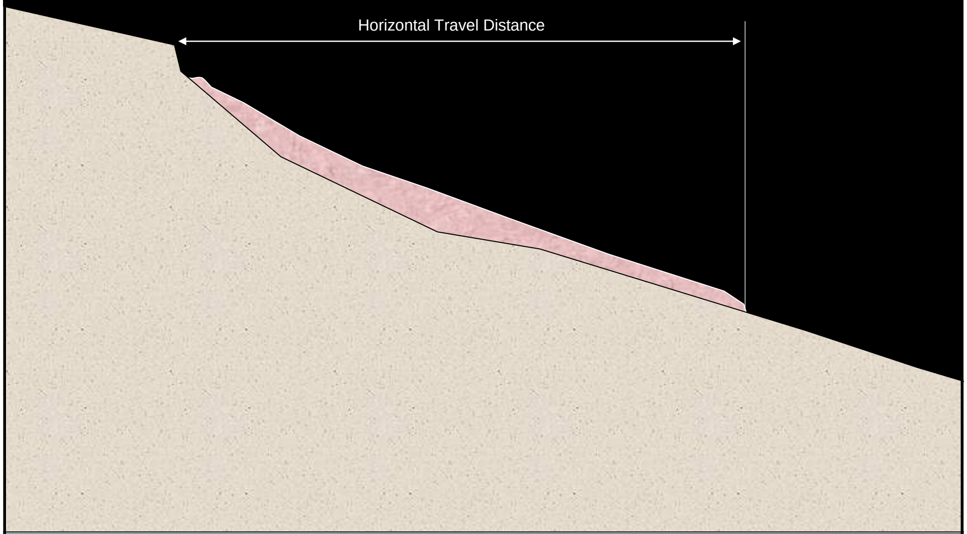
Landslide Debris Travel Distance



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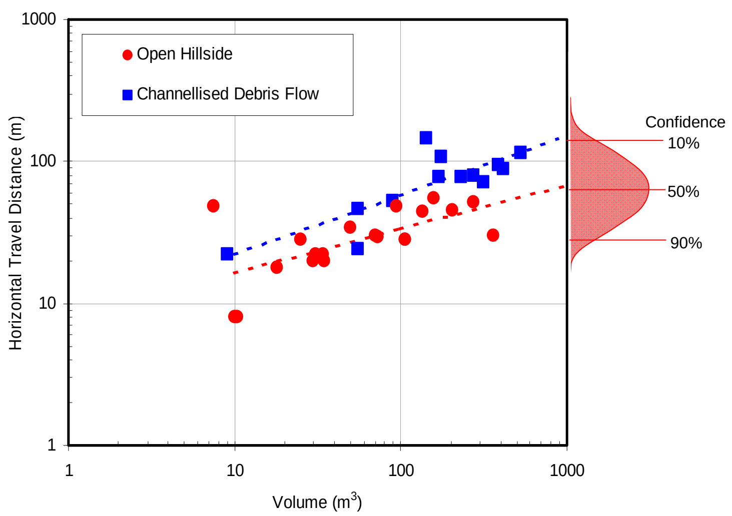
Observed Travel distances



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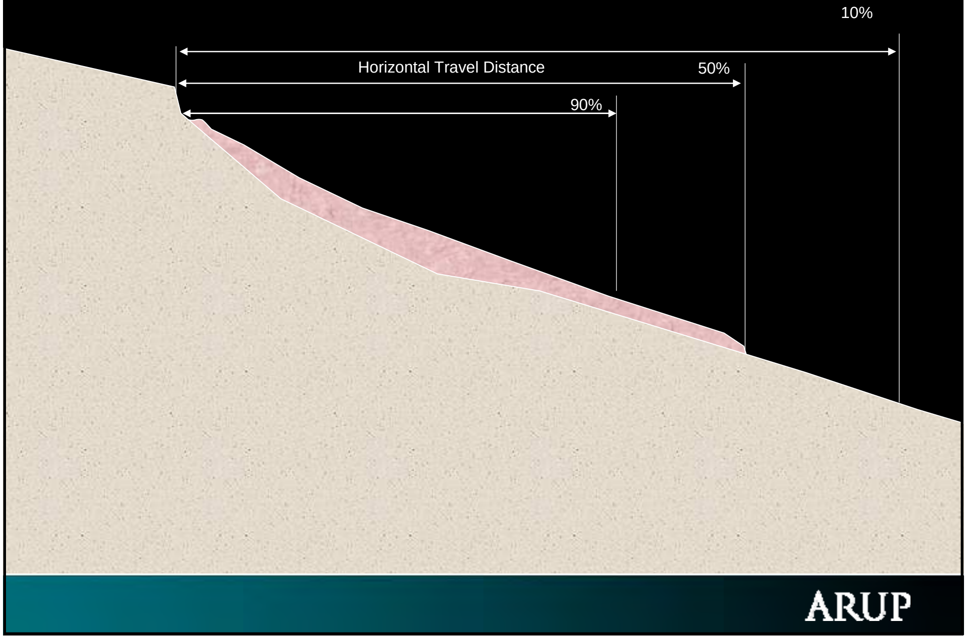
Landslide Debris Travel Distance



Design Event

GEO Report No 174

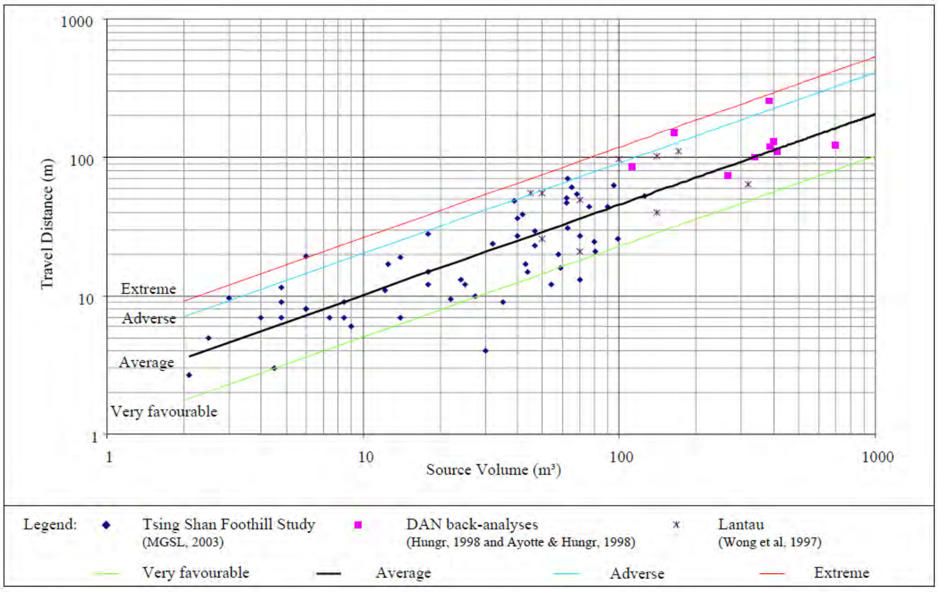
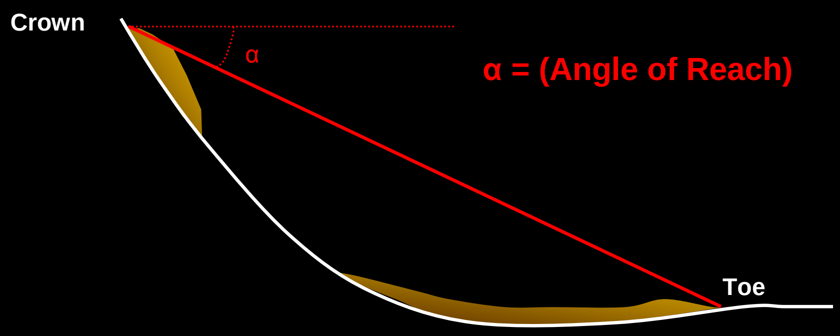


Figure A2 - Travel Distance Vs. Landslide Volume for Open Hillslope Failures

Debris Run-out (Empirical Approach)

- Travel Angle or Angle of Reach Approach



- Typically assessed based on area specific case histories

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Design Event

GEO Report No 174

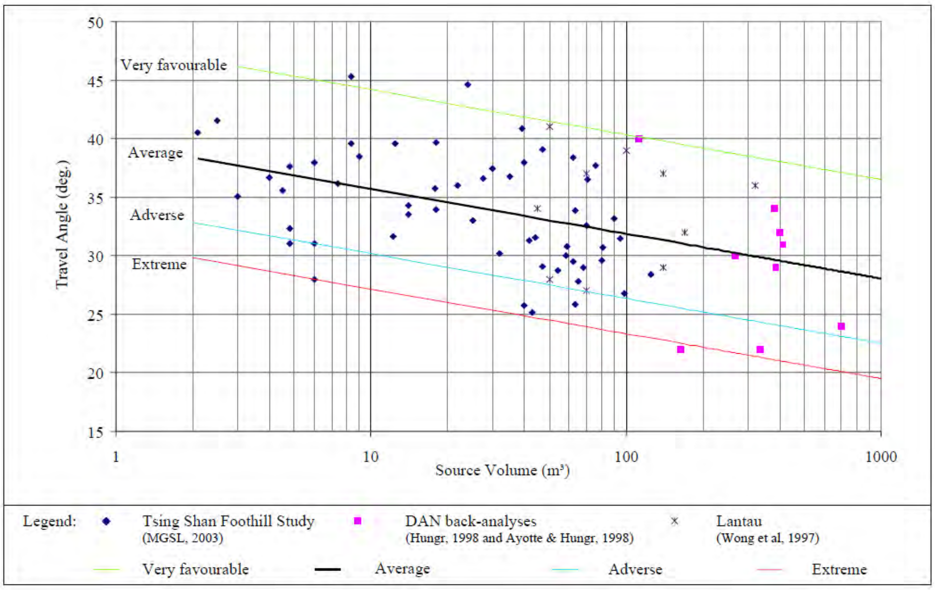

Figure A1 - Travel Angle Vs. Landslide Volume for Open Hillslope Failures

Design Event

GEO TN 7/97

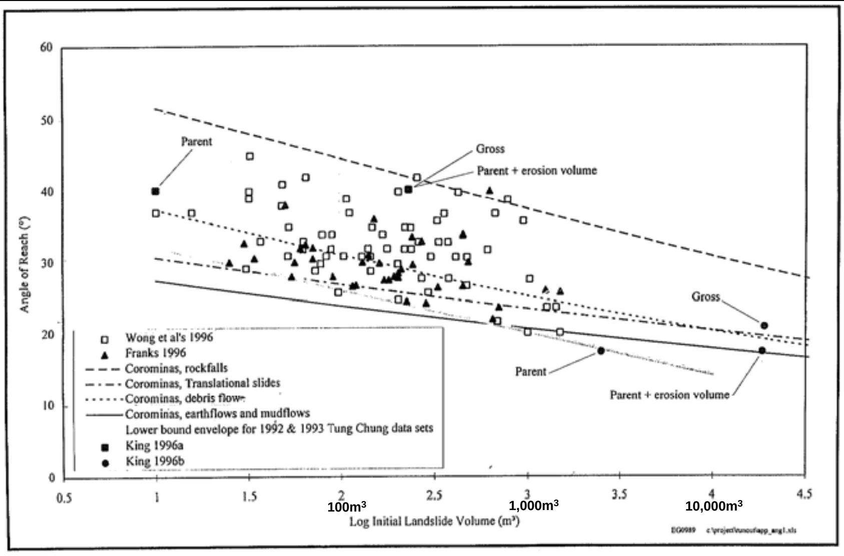

Figure 10a - The Lower Bound Envelope of Angle of Reach

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Design Event

GEO Report No 174

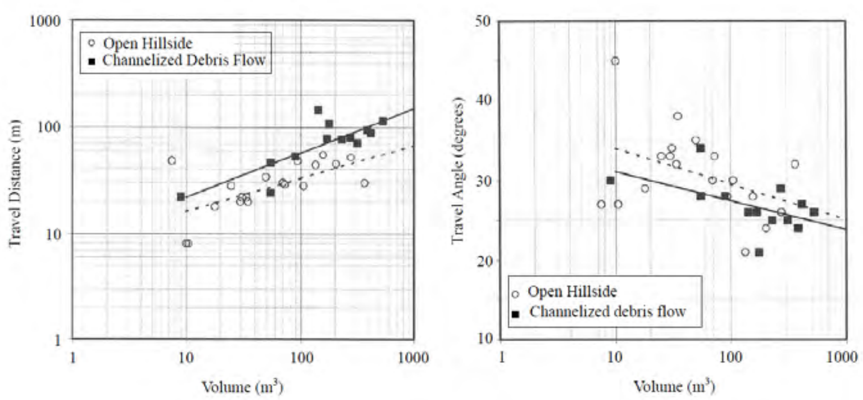

Figure 5.23 - Mobility of Landslides in Pat Heung (based on OAP, 2003)

Run-out Trail Definition

- Run-out trails initially based on GIS generated Digital Elevation Models (DEM)
- DEM’s only as accurate as the survey data used to generate them
- Field verification often required
- Detailed site-specific topographic surveys greatly enhance the accuracy of any modelling.
- LiDAR very important

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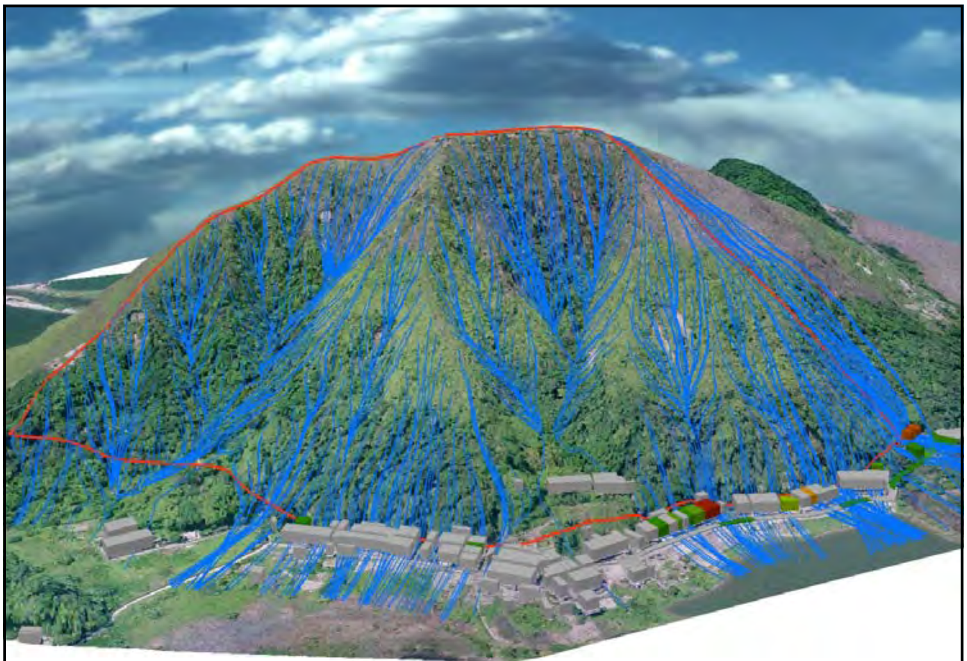

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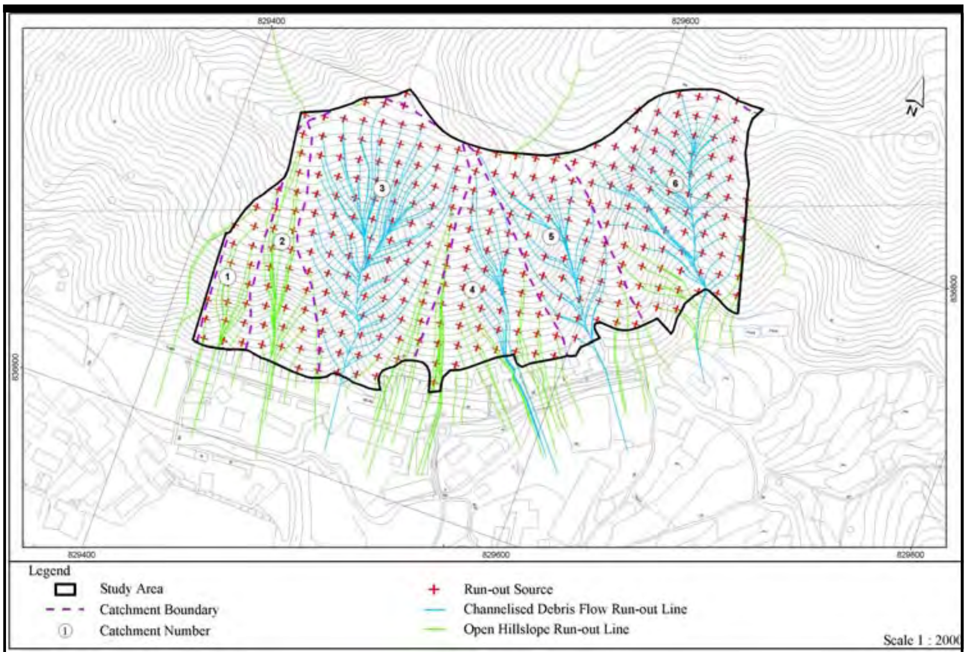

Landslide Trajectories and Runout

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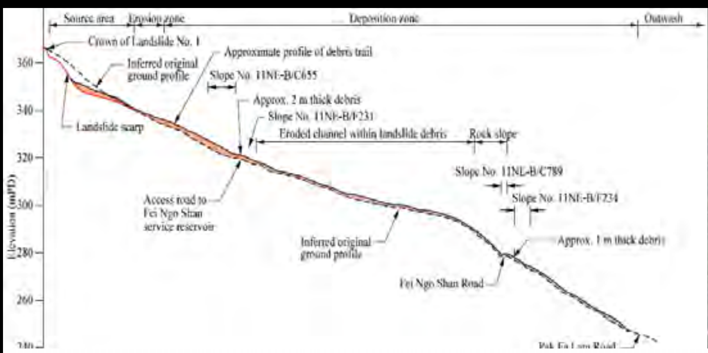
Debris Path & Mass Balance

- Record debris entrainment and deposition thickness along the run-out trail



0–13	13–42	42–53	53–91	91–95	95–106	106–145	145–170	170–208	208–224	224–228	228–260	260–282	282–288	Chainage (m)
3850#														Bulked Volume (m^3)
	150	25												Erosion (m^3)
	285	170	885	200	455	945	510	215	30	100	110	100*	12	Deposition (m^3)
	3715	3570	2685	2485	2030	1085	575	360	330	230	120	20	8	Mass Balance (m^3)

* denotes outwash # denotes Bulked volume = source volume x 1.15

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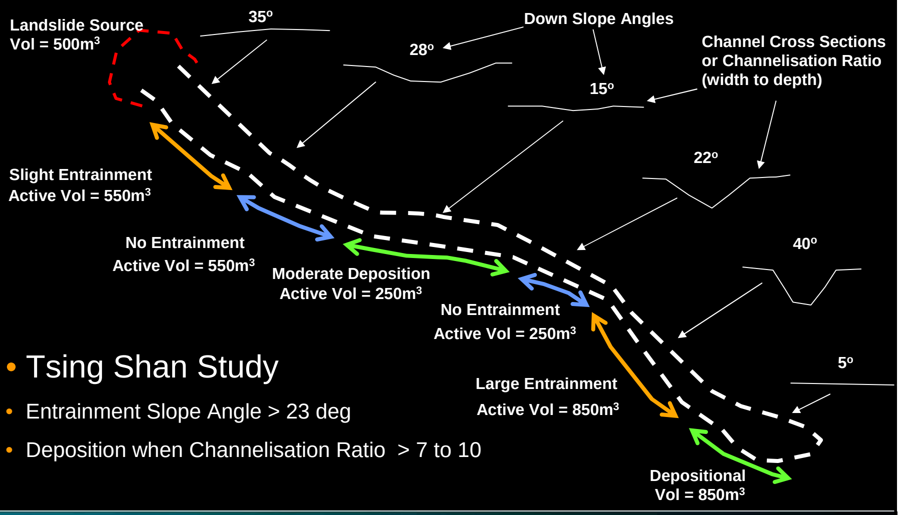
Debris Path & Mass Balance

- Mass Balance Approach (Active Volumes)



- Tsing Shan Study
- Entrainment Slope Angle > 23 deg
- Deposition when Channelisation Ratio > 7 to 10

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Debris Path & Mass Balance

- Back Analysis of Previous Landslide

Back Analysis of the 1993 Multiple Source Channelised Debris Flow

Channelised Debris Flow 29
Design Source Volume 1163 m³
Volume at Channel[1] 743 m³

Section	Chainage (m)	Length (m)	Width (m)	Depth (m)	Inclination (degrees)	Side Slopes (degrees)	Channel Ratio	Mode	Regolith Depth (m)	Erodible Rating	Erodible Depth (m)	Debris Height (m)	Entrainment Rate (<45) (m3/m)
12	0.0	57.0	30.0	1.0	28	15	30.0	D	1	0.0	0.0	1.0	0.0
11	57.0	122.0	4.0	1.0	23	45	4.0	T	1	0.5	0.5	1.0	0.0
10	179.0	24.0	5.0	2.0	19	80	2.5	T	1	0.5	0.5	2.0	0.0
9	203.0	32.0	2.7	1.4	10	45	1.9	D	2	0.5	1.0	1.4	0.0
8	235.0	21.0	3.5	2.0	15	70	1.8	D	2	0.5	1.0	2.0	0.0
7	256.0	22.0	1.5	0.6	12	70	2.5	D	1	0.5	0.5	0.6	0.0
6	278.0	20.4	5.0	1.3	20	60	3.8	T	2	0.0	0.0	1.3	0.0
end	452.5												

Notes: 1. Mode: E Erosion
D Deposition
T Transition
2. Erodibility Rating: Recent Landslide Debris and Valley Colluvium 0.5
Saprolite and Bedrock 0
3. It has been assumed that 20% of the source volume of landslides 29.2/1-1993-1, 2,3,4,5 and 6 remained in the area between the source zone and the channel.
4. It has been assumed that 80% of the debris from landslides 29.2/1-1993-7, 9 & 10 was deposited before reaching the drainage channel
4. For channels with side slopes of > 45°, it was assumed that a CDF would entrain material to a 'u'-shaped profile with nearly vertical sides and a flat base
5. For channels with side slopes of < or = 45°, it was assumed that a CDF would entrain material to a 'v'-shaped profile with the maximum depth of the 'v' being

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Debris Path & Mass Balance

- Back Analysis of Previous Landslide

Back Analysis of the 1993 Multiple Source Channe

Channelised Debris Flow 29
Design Source Volume 1163 m^3
Volume at Channel[1] 743 m^3

Section	Chainage (m)	Length (m)	Width (m)	Deposition Rate (<45) (m3/m)	Deposition Rate (>45) (m3/m)	Channel Deposition Vol. (m3)	Flood Bank Deposition Vol. (m3)	Debris Fan Deposit Vol. (m3)	Active Vol. (m3)
12	0.0	57.0	30.0	-3.7	0.0	-212.7	0.0		530.3
11	57.0	122.0	4.0	0.0	0.0	0.0	0.0		530.3
10	179.0	24.0	5.0	0.0	0.0	0.0	0.0		530.3
9	203.0	32.0	2.7	-2.0	0.0	-62.7	-16.0		451.6
8	235.0	21.0	3.5	0.0	-8.5	-177.6	0.0		274.0
7	256.0	22.0	1.5	0.0	-1.0	-22.7	-99.0		152.3
6	278.0	20.4	5.0	0.0	-7.5	-152.3	0.0		0.0
end	452.5							0.0	

Notes: 1. Mode: E Erosion
D Deposition
T Transition
2. Erodibility Rating: Recent L
Saprolite
3. It has been assumed that 20% of the sou
4. It has been assumed that 80% of the deb
4. For channels with side slopes of > 45°, i
5. For channels with side slopes of < or = 4

rainment depth.

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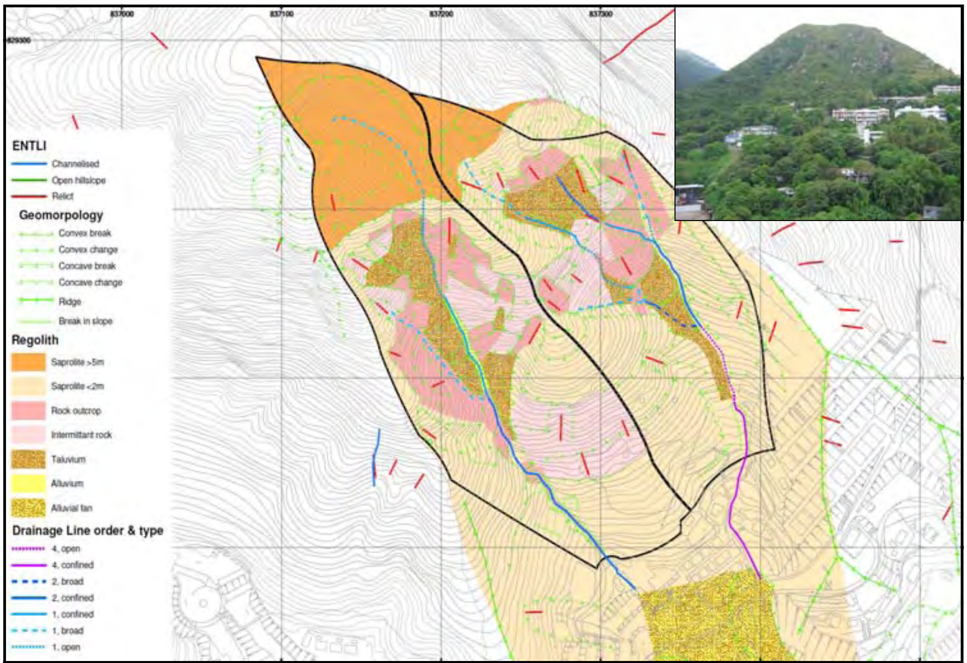

Example Site - Morphographical Map

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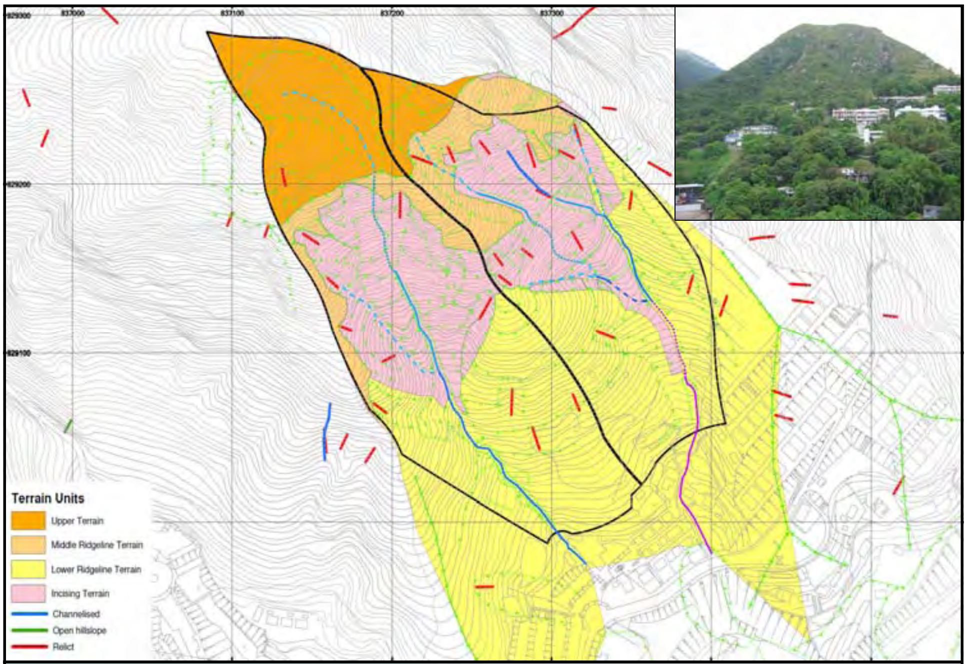

Example Site - Geomorphological Model (Terrain Unit Map)

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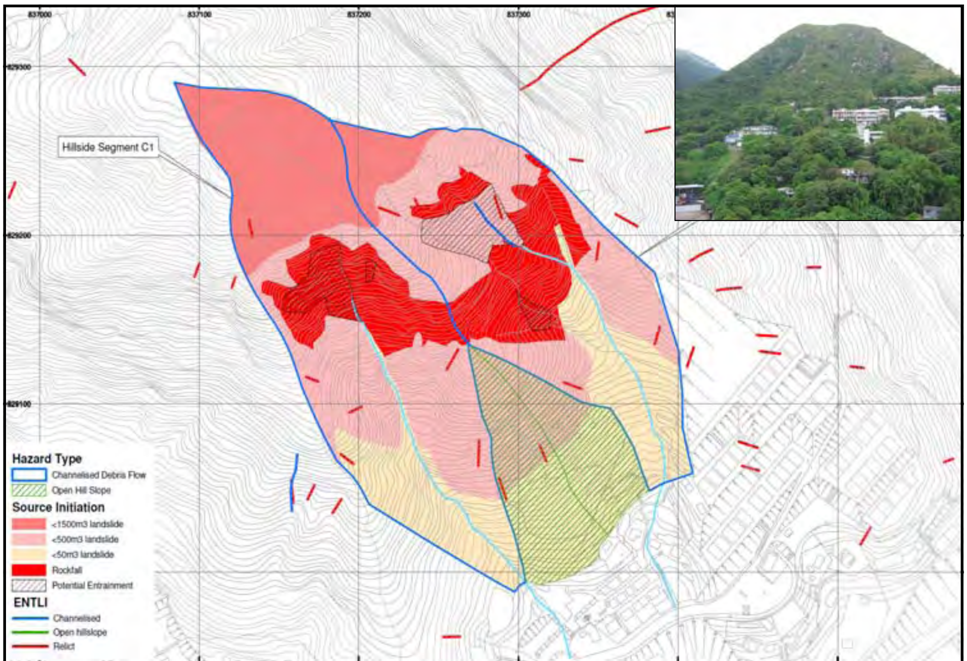

Example Site - Landslide Hazard Map

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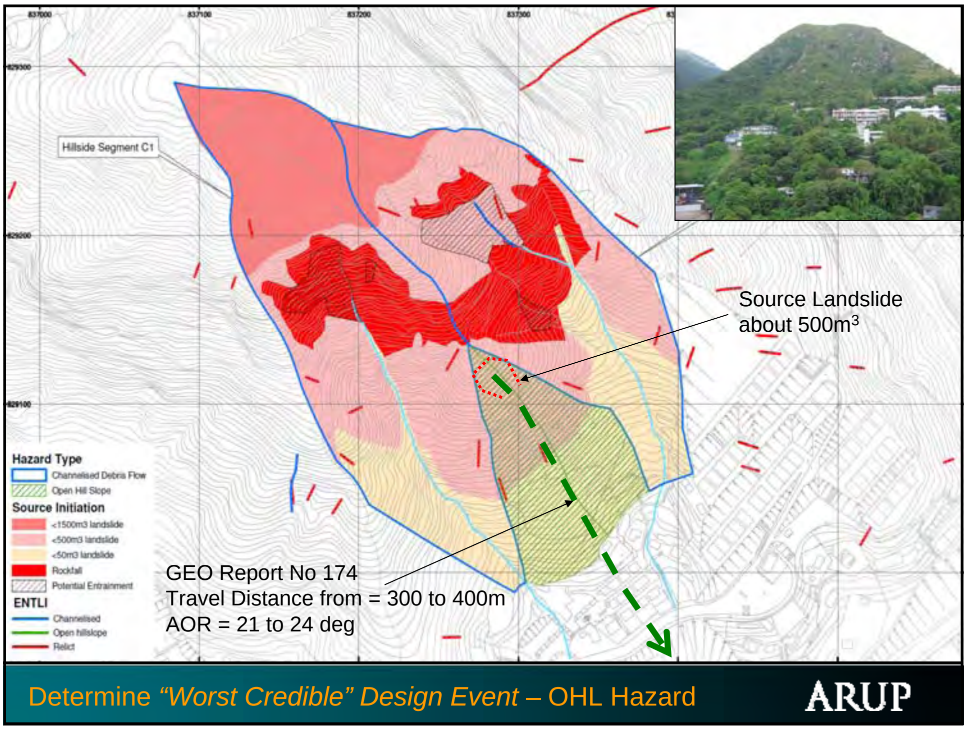
Hillside Segment C1
Source Landslide about 500m3
Hazard Type
Channelised Debris Flow
Open Hill Slope
Source Initiation
<1500m3 landslide
<500m3 landslide
<50m3 landslide
Rockfall
Potential Entrainment
ENTLI
Channelised
Open hillslope
Relict
GEO Report No 174
Travel Distance from = 300 to 400m
AOR = 21 to 24 deg
Determine "Worst Credible" Design Event – OHL Hazard
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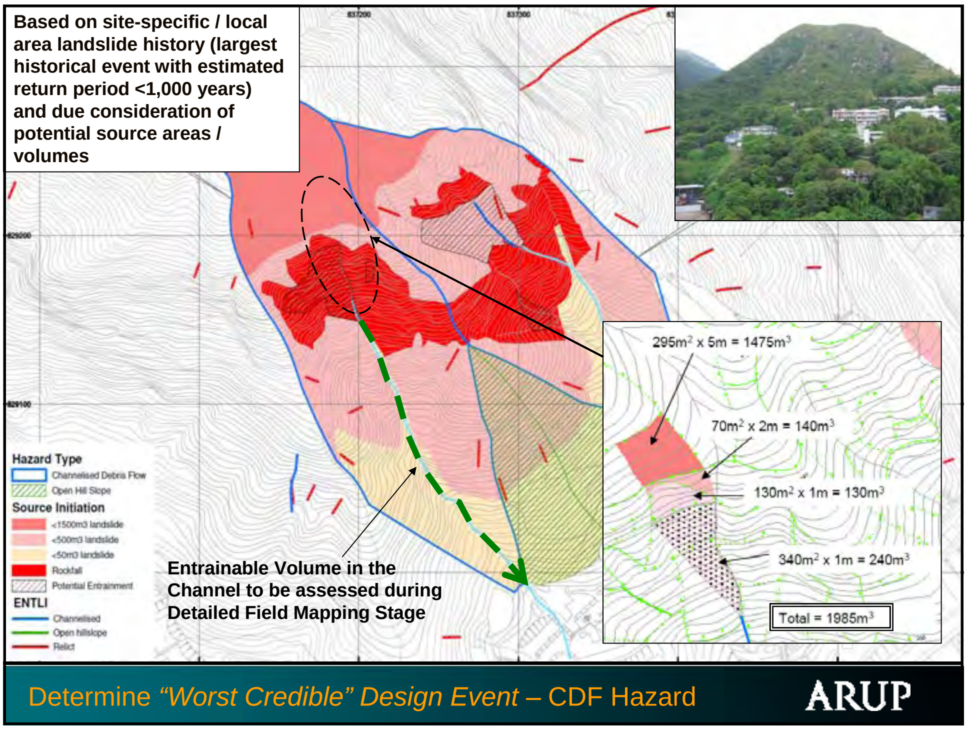
Based on site-specific / local area landslide history (largest historical event with estimated return period <1,000 years) and due consideration of potential source areas / volumes
295m2 x 5m = 1475m3
70m2 x 2m = 140m3
130m2 x 1m = 130m3
340m2 x 1m = 240m3
Total = 1985m3
Hazard Type
Channelised Debris Flow
Open Hill Slope
Source Initiation
<1500m3 landslide
<500m3 landslide
<50m3 landslide
Rockfall
Potential Entrainment
ENTLI
Channelised
Open hillslope
Relict
Entrainable Volume in the Channel to be assessed during Detailed Field Mapping Stage
Determine "Worst Credible" Design Event – CDF Hazard
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Mitigation Measures Strategy and Design

Passive or Active Mitigation Strategies

Passive

- Protect / relocate / avoid
- Early engagement / consultation required

Active

- Source Area
  - Soil nails, subsurface drainage, regrading etc.
- Deposition Area
  - Energy dissipation, fences, walls, containment barriers, deflectors etc.

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Mitigation Measures Strategy and Design

Input Parameters for Mitigation Design :

- Type of landslide hazard
- Volume or size of hazard / debris at proposed mitigation location
- GEO Report No 104 or Debris Flow analysis required for
  - Landslide velocity
  - Debris thickness and runup heights
  - Impact pressures / loads
  - etc

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Thank You