# Natural Terrain LANDSLIDE

## Hazards in Hong Kong

Geotechnical Engineering Office
Civil Engineering and
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## Foreword

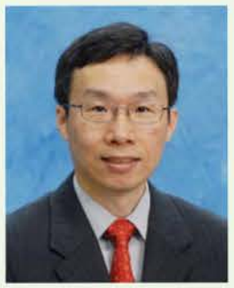
In recent years, extreme weather has brought about many disasters worldwide, including devastating landslides, causing significant casualties and economic losses.

Natural terrain covers over 60% of the land area of Hong Kong. Landslide risk, especially under extreme weather conditions, is real and significant. The record-breaking rainstorm on 7 June 2008 triggered over 2,400 natural terrain landslides in Lantau alone. It highlighted the potential vulnerability of developments near natural hillsides. This severe rainstorm resulted in fatalities, and havoc in western Lantau. The impact could be much more serious should the same hit the more densely developed areas.

The Geotechnical Engineering Office (GEO) under the Civil Engineering and Development Department completed the Landslip Preventive Measures (LPM) Programme in 2010. The overall landslide risk level arising from man-made slopes had been reduced to less than 25% compared to that of 1977, when GEO was established. A rolling Landslip Prevention and Mitigation Programme (LPMitP) was then launched to dovetail with the LPM Programme. The LPMitP systematically treats man-made slopes and mitigates natural terrain landslide risks and aims to keep landslide risks in Hong Kong within an As Low As Reasonably Practicable level in the long term.

Despite the Government's strenuous efforts to improve slope safety, given the climate, hilly terrain, dense population and continuing development in Hong Kong, there is always a risk that landslides with multiple fatalities or other serious consequences may occur should Hong Kong be hit by an extreme rainfall event. The concerted efforts of the Government and the general public are crucial in building the community's resilience against landslide disasters and reducing the potential loss of life and damage to property. I hope this book could serve to enhance public awareness of natural terrain landslide hazards as well as to remind all of us of the need to stay vigilant and be prepared.

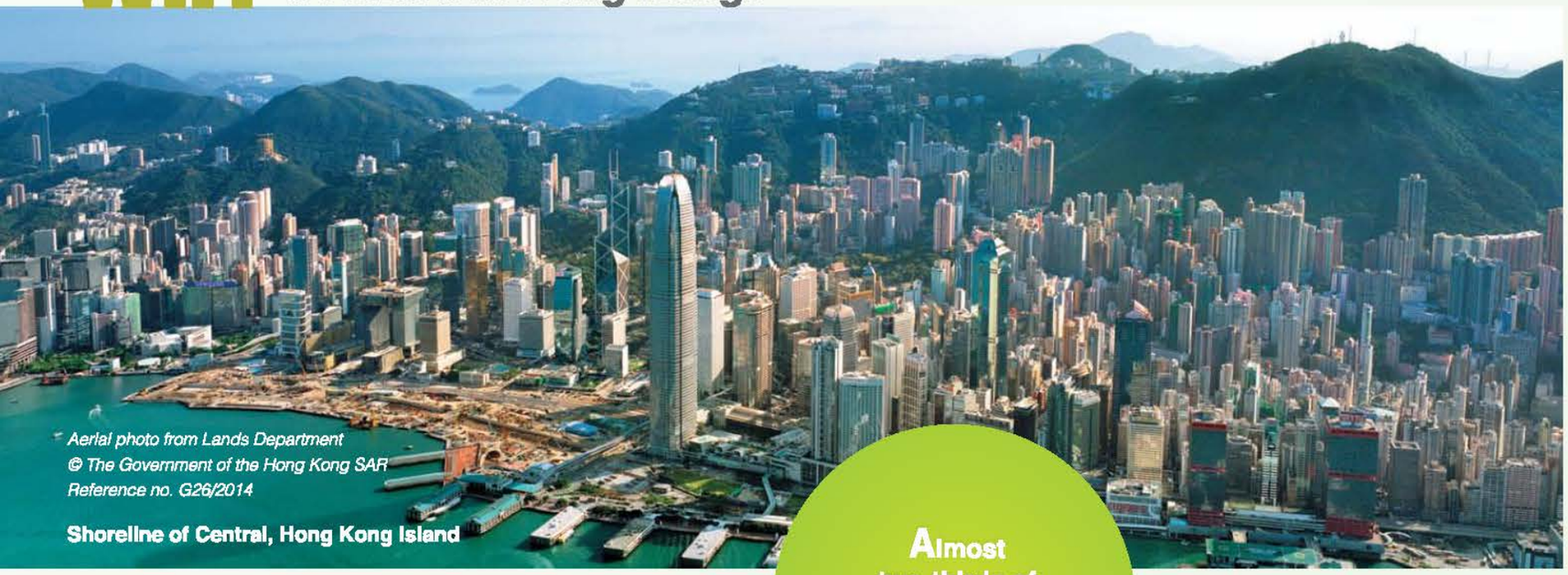
This book has been prepared by Dr K C Ng and Ms H Y Ho together with Mr Rick C K Tam, Ms Becky L S Lui and Ms Candy Y M Cho. Their contributions are gratefully acknowledged.



H N Wong
Head of the Geotechnical Engineering Office
Civil Engineering and Development Department
March 2016

## The five Ws and one H for Natural Terrain Landslides

# WHY are "Natural Terrain Landslides" a Hazard in Hong Kong?



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**Shoreline of Central, Hong Kong Island**

**Almost two-thirds of Hong Kong is "natural terrain".**

**"Natural terrain" is the term used in Hong Kong for hillsides that have not been substantially modified by human activities.** Slopes that have been formed by human activities by cutting into hillsides or by earth-filling (including cut slopes, fill slopes and retaining walls) are defined as man-made slopes. Sizeable man-made slopes are registered in the catalogue of slopes by the Geotechnical Engineering Office (GEO), Civil Engineering and Development Department. The catalogue currently contains about 60,000 registered man-made slopes.

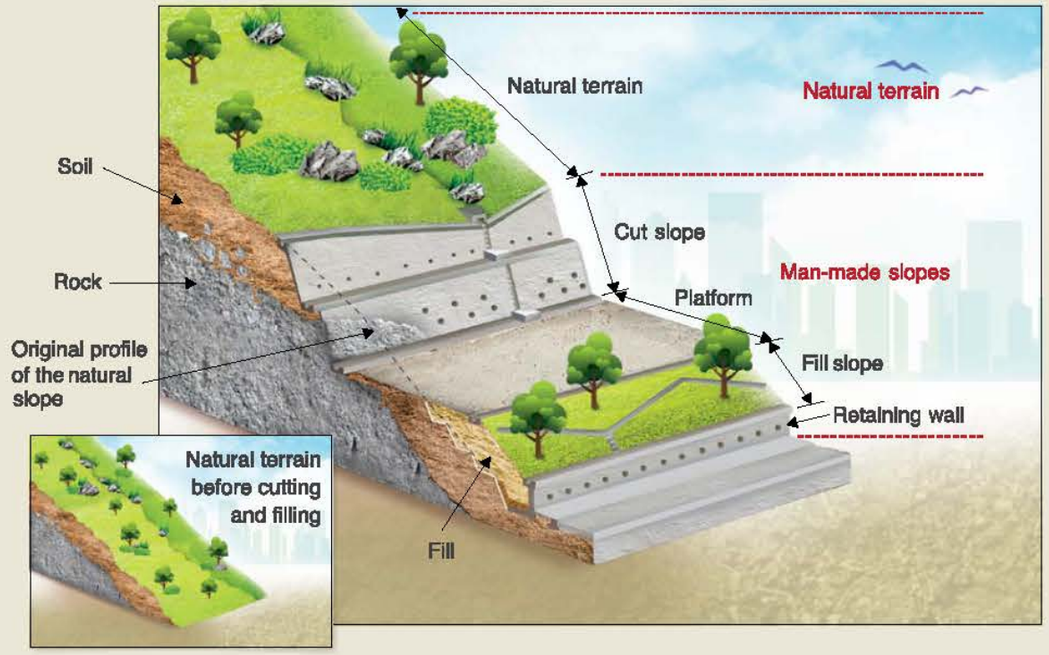
*Natural terrain landslides at North Lantau*

We think of Hong Kong as a densely developed city, but in fact **over 60% of the total land area is natural terrain.** Our urban development, and hence the population, is mainly located on or close to steep hillsides.

The demand for housing and other infrastructure means that urban development is encroaching further and further onto areas of steeper natural terrain. Natural terrain landslide is a natural phenomenon. Their potential threat on urban development has led to the study of the hazards and ways to mitigate the risks.


*Photo illustrating relationship between man-made slope and natural terrain*

## Man-made slopes and natural terrain



Natural terrain landslide hazards are not far from us. There are recent examples of natural terrain landslides in Hong Kong and our neighbours.

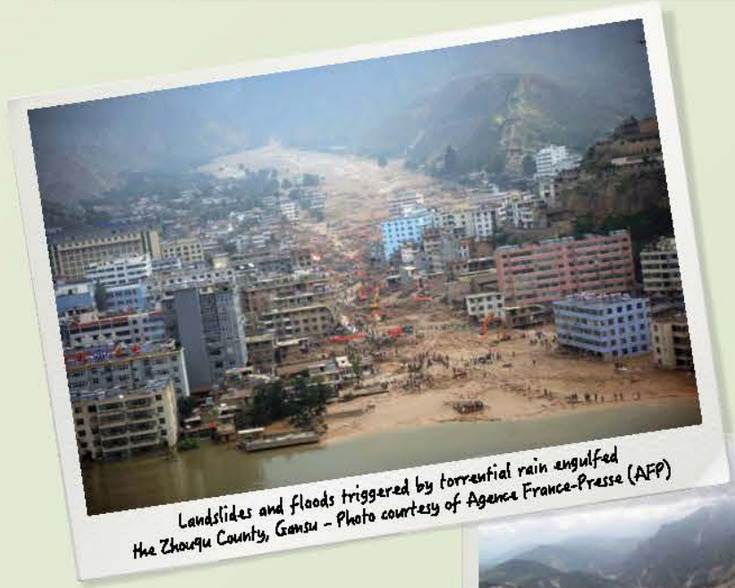
## Recent examples of natural terrain landslides in Hong Kong

Natural terrain landslides in Cantau induced by the 7 June 2008 rainstorm

Natural terrain landslides near University Station at Sha Tin affecting railway tracks on 2 July 1997

## Recent examples of natural terrain landslides in the region

| Date | Location | Details |
|---|---|---|
| Oct 2013 | Island of Izu Ōshima, Japan | Heavy rain associated with typhoon Wipha triggered a massive landslide on island of Isu Ōshima, killing at least 31 persons and leaving 13 others missing. |
| Sep 2013 | Philippines | Landslides in the Philippines killed 20 people in mountainside villages after powerful monsoon rains pummeled the country's northwest region. |
| Jul 2011 | Seoul, South Korea | Torrential rain (about 500 mm rainfall within 3 days) resulted in widespread flooding and landslides. There were more than 30 reported fatalities and about HK$1,600 million in economic loss. |
| Aug 2010 | Gansu, Mainland China | Landslides and floods triggered by torrential rain engulfed the Zhouqu County, with 1765 people killed/missing. |
| Aug 2009 | Village of Xiaolin, Taiwan | Typhoon Marakot landed Taiwan dumping record-breaking heavy rains. The entire village of Xiaolin in southern Kaohsiung county was buried by landslide debris killing 439 people. |



Landslides and floods triggered by torrential rain engulfed the Zhouqu County, Gansu – Photo courtesy of Agence France-Presse (AFP)

The entire village of Xiaolin, Kaohsiung was buried by landslide – Photo courtesy of Soil and Water Conservation Bureau, Taiwan

# WHAT Happened to Our Natural Terrain?


Oblique aerial photo of one of the landslides above Shek Pik Reservoir in 2008

Photo of the landslide scar taken at Point A of the left photo (note the size of the landslide with reference to that of the group of people in the photo (red arrow))

**On average, about 300 natural terrain landslides occur every year, with widespread occurrences every 10-15 years.**

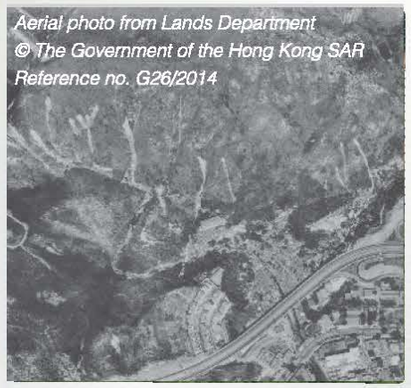
How many natural terrain landslides do you think occur in Hong Kong each year? It may come as a surprise that, based on aerial photograph interpretation, **on average about 300 landslides occur on natural terrain each year in Hong Kong!**

People often underestimate the number of natural terrain landslides as many occur on hillsides away from urban areas. About 1,500 natural terrain landslides were reported to the GEO between 1982 and 2013, mostly affecting open spaces, minor roads, footpaths, and other less important facilities. These landslides occur close to built-up areas and these are what the general public are usually aware of. In fact, based on aerial photograph interpretation, a total of 13,700 natural terrain landslides occurred from 1982 to 2013.

**The natural terrain landslides in Hong Kong are usually of small-to-medium scale,** with volumes up to several hundred cubic metres. That is about a quarter of the size of a 2500 m³ Olympic-sized swimming pool. Large landslides are usually related to adverse geological conditions or scraping/transportation of loose deposits on channel beds along the landslide flow paths, which add significant volume of debris to the initially small landslide, such as in several landslides above Shek Pik Reservoir in 2008 and the Tsing Shan debris flow in 1990. **Although large-scale landslides are relatively rare, when they occur close to urban area, the consequences can be dire.**

1990 Tsing Shan debris flow





*Aerial photo from Lands Department*
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Widespread natural terrain landslides near Sham Tseng San Tsuen after 1982 rainstorms

So what is the main trigger of natural terrain landslides? Hong Kong's natural terrain landslides are mainly rain-induced. **Widespread landslides occur in very intense and heavy rain.** Rainfall and landslide data show that natural terrain landslides tend to become widespread when the rain is very intense, with a "normalised 24-hour rainfall"* of over 20%. Hong Kong's records in the past 50 years suggest that widespread natural terrain landslides tend to occur almost once every 10 to 15 years.

* "Normalised 24-hour rainfall" is defined as the maximum rainfall in a rolling 24-hour period divided by the mean annual rainfall of that location.
For example for a particular rainstorm over Hong Kong Island:
Highest rolling 24-hour rainfall = 400 mm
Mean annual rainfall for Hong Kong Island = 2000 mm
Normalised 24-hour rainfall = 20%

16 years

**June 1966** – A heavy rainstorm affected Hong Kong Island (normalised 24-hour rainfall from 10% to 25%), triggering around 150 natural terrain landslides over some 45 km² of natural terrain on Hong Kong Island alone.

11 years

**May and August 1982** – Hong Kong was battered by two intense rainstorms (normalised 24-hour rainfall from 5% to 25%), which led to some 1,800 natural terrain landslides, resulting in nine fatalities.

15 years

**November 1993** – Lantau Island suffered about 840 natural terrain landslides following a severe rainstorm (normalised 24-hour rainfall from 10% to 35%). Luckily, there were no serious consequences, apart from blockage of roads and catchwaters.

**June 2008** – The date 7 June 2008 will long be remembered in Hong Kong for one of the most severe rainstorms in decades. The western part of Lantau Island was most severely hit (normalised 24-hour rainfall from 20% to 30%), resulting in more than 2,400 natural terrain landslides on Lantau Island. Several key roads that provide the sole access to remote rural communities were blocked by landslide debris, and over 25 houses had to be evacuated. The highway to the airport was closed for 16 hours. Had the severe rainstorm been over more densely populated areas, the consequences could have been far more serious.

1993 Lantau, rain-induced shallow natural terrain landslides

Landslide clusters in West Lantau after the June 2008 rainstorm

# WHERE were these Natural Terrain Landslides?

Aerial photographs provide an excellent way to understand the distribution and nature of natural terrain landslides, hence better assessment of the hazards. In 1995, GEO began compiling an inventory of natural terrain landslides using high-flight aerial photographs taken from at least 2,400-m flight-height.

**The current catalogue, named the "Enhanced Natural Terrain Landslide Inventory" (ENTLI), was compiled by using both low- and high-flight aerial photographs**, including those dating back to 1924. The ENTLI is presented in a Geographic Information System (GIS) data format containing the locations and attributes of about 20,000 recent landslides that can be determined from aerial photographs and another 90,000 relict landslides which predate the earliest available aerial photographs. The inventory is updated every three years or so.

This is one of the most comprehensive inventories of natural terrain landslides that have been compiled at metropolitan level. The ENTLI provides vital information for assessment of the distribution, characteristics and hazards of natural terrain landslides in Hong Kong.

**GEO has compiled one comprehensive inventory of natural terrain landslides & another one for catchments with historical landslides.**

*About 90,000 relict landslides in ENTLI in Hong Kong (green marks)*

*About 20,000 recent landslides in ENTLI in Hong Kong (red marks)*



WHERE

**Example of HLCs delineated**

**Vulnerable catchments are those that pose natural terrain landslide risks to existing developments.** A Historical Landslide Catchment (HLC) is a type of vulnerable catchments where natural terrain landslides identified in ENTLI have occurred close to existing buildings or important transport routes. HLCs contribute a notable amount of the overall risk of natural terrain landside. They are given priority in the GEO's current work.

An HLC inventory has been developed, and it consists of hillside catchments. **About 2,800 HLCs have been identified and recorded in the inventory up to 2013. Like ENTLI, this HLC inventory is updated regularly.**

**It is important to note that landslides can and do sometimes occur on hillsides without a history of failures!**

## Types of Natural Terrain Landslides at Different Settings

- On a relatively planar hillslope, debris of an **open hillslope landslide** slides down either as an intact slab or it may disintegrate as it moves. The former is generally referred to as a debris slide; the latter as a debris avalanche.

- At an incised drainage catchment, when a landslide occurs, debris within the catchment enters the drainage line to form a **channelised debris flow**. The drainage line governs the debris flow path. As the landslide debris travels downslope along the drainage line, it mixes with surface water. This tends to be more hazardous than open hillslope landslide as the debris is more mobile and therefore has a higher potential to reach developed areas.

- Where the hillside contains a pronounced topographic depression (land that is sunken below the surrounding area) and does not have a definite flow path, landslide commonly happens in the form of a **mixed debris avalanche and debris flow**.

- Where landslide debris enters a stream, a debris flow can develop into a **debris flood** as it mixes with more and more water and travels by the dominant mechanisms of stream flow. Debris floods are generally very mobile.

- Where there is a loose boulder/rock cliff, a **boulder/rock fall** may occur, involving movement downslope in the form of free fall through the air, sliding, leaping and rolling.

Open hillslope landslide

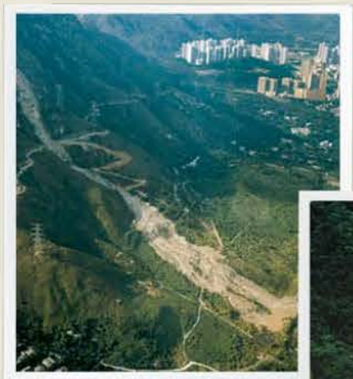
Channelised debris flow

Debris flood

WHERE

## Some notable natural terrain landslides

| Year | Location | Landslide type | Volume of landslide debris involved ($m^3$) | Consequence |
|---|---|---|---|---|
| 1990 | Tsing Shan | Channelised debris flow | 20,000 | Did not result in serious consequence. Land use of the site below the landslide was subsequently amended from residential development to a golf driving range. |
| 1995 | Shum Wan Road | Open hillslope landslide (partially triggered by man-made influences) | 26,000 | Severely damaged three shipyards and a factory on the sea front. Two fatalities and five injured. |
| 1999 | Sham Tseng San Tsuen | Channelised debris flow | 600 | Demolished several dwellings. One fatality and 13 injured. |
| 2001 | Lei Pui Street | Channelised debris flow | 780 | Demolished two squatter structures. Lei Pui Street was closed for three days. |
| 2008 | Yu Tung Road | Channelised debris flow | 3,500 | Both westbound lanes of Yu Tung Road were closed for more than two months. |
| 2008 | North Lantau Highway | Debris flood | 780 | Severe flooding of a 200 m section of North Lantau Highway (NLH). The westbound lanes of the NLH, which are the sole vehicular access to the Hong Kong International Airport, were temporarily closed for about 16 hours. |



1990 Tsing Shan Channelised debris flow

1995 Shum Wan Road landslide

1999 Sham Tseng San Tsuen channelised debris flow

2008 Yu Tung Road channelised debris flow

# WHEN should I be Concerned with Natural Terrain Landslide Hazards?

**Clouds over Victoria Harbour**

**Climate change, extreme rainfall & more & more developments close to hillsides all play a part to increase natural terrain landslides risk in Hong Kong.**

Most landslides in Hong Kong are triggered by rainfall. **According to past experience, when a sizeable area of natural terrain in Hong Kong has a normalised 24-hour rainfall greater than 20%, widespread natural terrain landslides tend to occur.**

**For a relatively smaller area or lower rainfall intensity, there may still be isolated natural terrain landslides.** The 1990 Tsing Shan debris flow is an example of an isolated large scale natural terrain landslide triggered by moderately heavy rainfall (normalised 24-hour rainfall <10%).

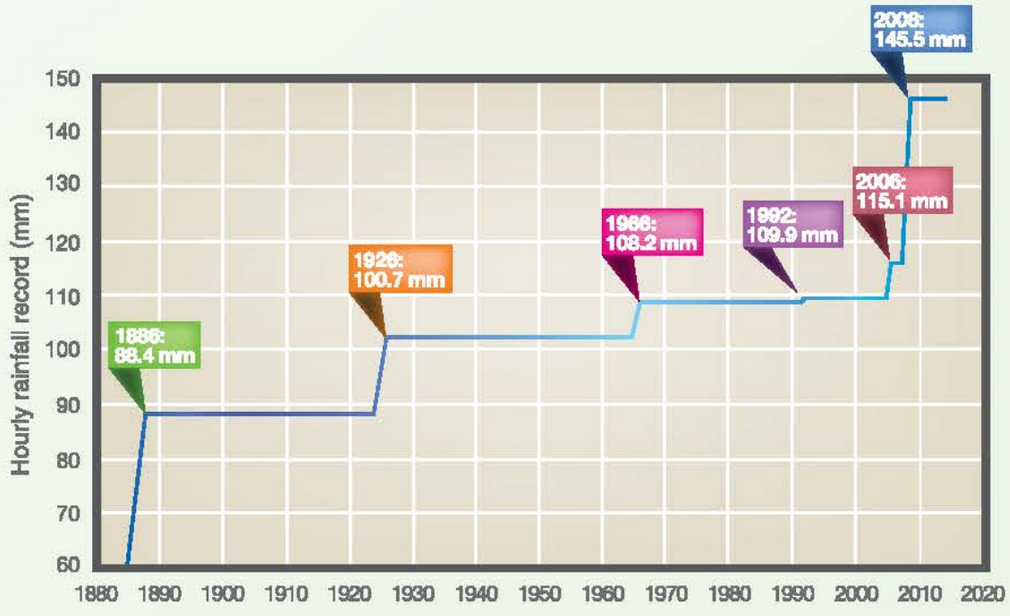
**Climate change has become a major challenge of our time.** In 2013, the United Nations Intergovernment Panel on Climate Change (IPCC) affirmed in its Fifth Assessment Report that the rise in atmospheric greenhouse gas concentration as a result of human activities is extremely likely to be responsible for the observed global warming since the middle of the 20th century.

Global warming can lead to an increase in the water-holding capacity of the atmosphere. Increase in water vapour provides more favourable conditions for developing intense rainstorms and hence increases the chance of widespread natural terrain landslides occurring.





Hong Kong experienced a historical rainstorm on 7 June 2008 with a recorded hourly rainfall of 145.5 mm, that was almost double the record of 88.4 mm in 1886.




**Hourly rainfall record at the Hong Kong Observatory**

## Projected changes in extremely wet and extremely dry years

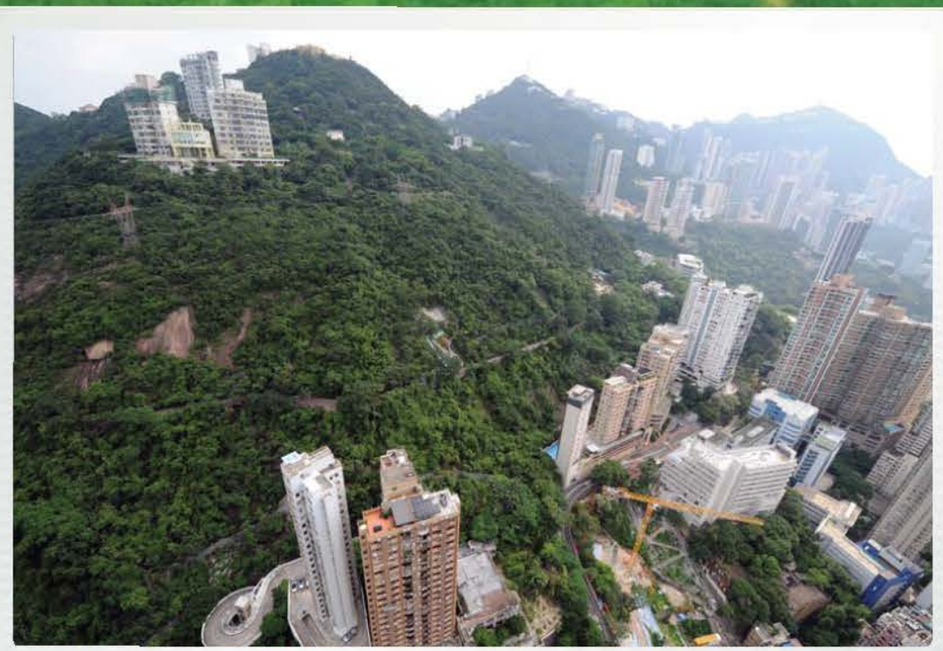
| | Observation in 1885 – 2005 | Projection for 2006 – 2100 |
|---|---|---|
| Extremely wet years (Annual rainfall > 3,168 mm) | 3 | 12 |
| Extremely dry years (Annual rainfall < 1,289 mm) | 2 | 2 |

Note: Data from the Hong Kong Observatory

According to a recent study of the Hong Kong Observatory, the frequency of occurrence of heavy rain events (hourly rainfall of 100 mm or more) has doubled in the past 100 years.

In other words, **the intensity and frequency of extreme rainfall events are poised to increase.**

The June 2008 landslides on natural terrain above Tai O San Tsuen, Lantau Island



A view of the natural terrain around Bowen Road highlighting the dense and close proximity of development

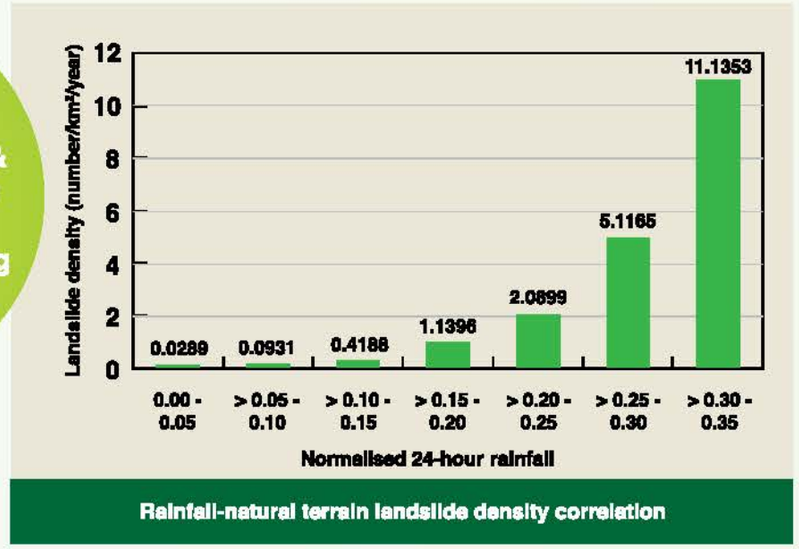
The June 2008 landslide on natural terrain above The University of Hong Kong

Urban expansion is increasingly encroaching onto areas close to steep natural terrain. **Coupled this with the likelihood of more extreme weather as a result of climate change, we have to stay vigilant about the risk of natural terrain landslides.** Given that some 2,400 natural terrain landslides occurred on Lantau Island during the severe rainstorm of 7 June 2008, one could imagine that should this intense rainstorm hit a densely populated area, **it could have resulted in dire consequences with multiple fatalities.**

The June 2008 landslides on natural terrain above Keung Shan Road, Lantau Island

# HOW are Natural Terrain Landslide Hazards Assessed ?

**State-of-the-art knowledge, risk management strategy & technology are used in Hong Kong, but limitations on predicting landslides remain.**




Rainfall-natural terrain landslide density correlation

## Rainfall-Natural Terrain Landslide Correlation

It is necessary to understand how rainfall affects hillside stability and the mobility of landslide debris so as to assess the natural terrain landslide hazards. The ENTLI and detailed rainfall records available in Hong Kong since 1985 have provided the essential data for GEO to establish a state-of-the-art rainfall-natural terrain landslide correlation. As shown in the chart, **the number of natural terrain landslides increases exponentially with rainfall intensity.**

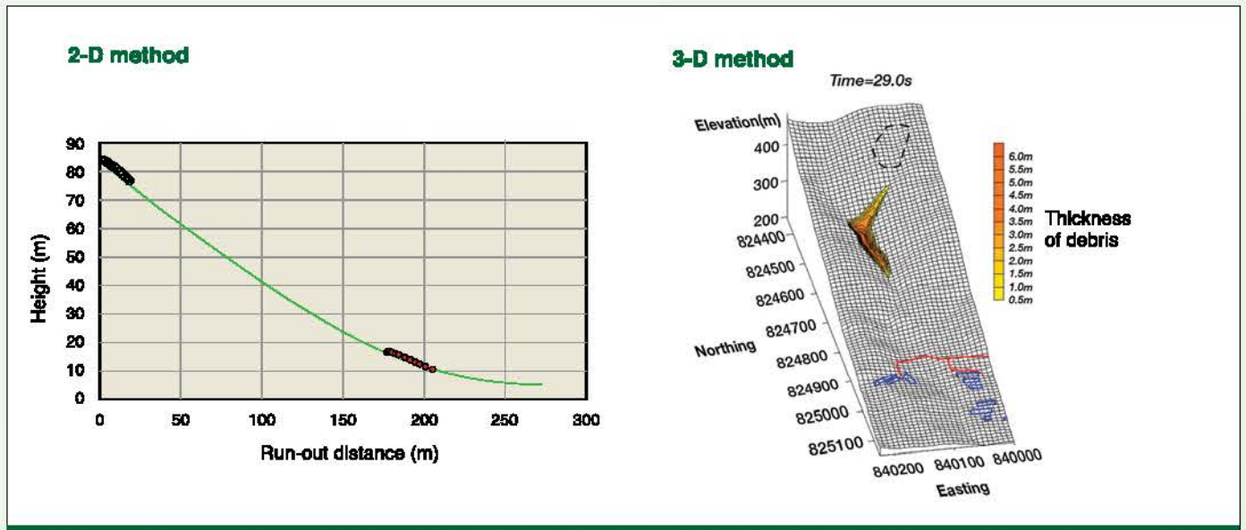
## Susceptibility Model

Generic susceptibility models have been developed since the 1990s to assess the likelihood of landslides occurring. Studies indicate that volcanic terrain is generally more susceptible to landslides than granitic terrain. Hillsides with slope gradients of between 30° and 40° are particularly vulnerable.

These models may be used, together with historical landslide records and other relevant terrain information, for reviewing landslide susceptibility of natural terrain.

## Limitations

Even with specialist input and state-of-the-art knowledge and practice, **there are inevitable uncertainties and technical difficulties** (e.g. ground conditions, rainfall and groundwater, etc.) **in predicting the exact number, time, location and scale of natural terrain landslides, especially when extrapolating to extreme rainstorm events.**



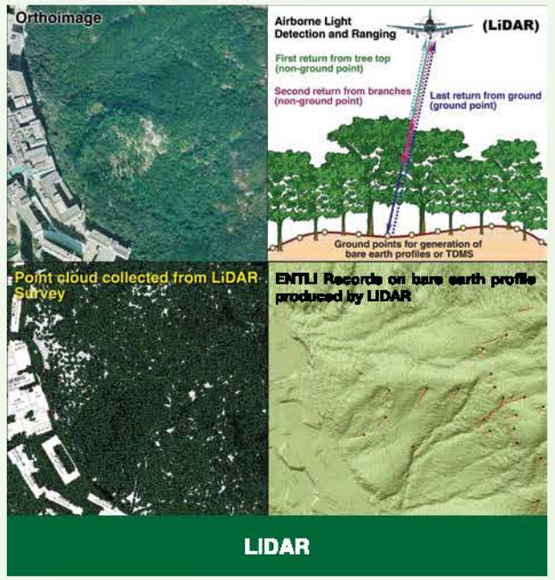

Debris run-out numerical modelling



## Natural Terrain Hazard Study (NTHS)

**An NTHS aims to identify natural terrain hazards that may affect a particular site and to propose mitigation strategies if necessary.** An NTHS typically involves desk study, field mapping, ground investigation, terrain classification, formulation of hazard map and design of the magnitude of hazard to be mitigated (please refer to GEO Report No. 138 for details).

State-of-the-art technology is deployed to carry out an NTHS, for example:




LIDAR

### Aerial Photograph Interpretation (API) & Airborne Light Detection and Ranging (LIDAR)*

Site-specific assessment can help to identify terrain that is showing signs of distress, such as cracks, that precede a landslide. Detailed interpretation of aerial photographs is useful in identifying these signs but is often hindered by thick vegetation. Nevertheless, GEO has made notable advances in the application of **remote-sensing technology, such as airborne Light Detection and Ranging (LiDAR), which renders high-resolution ground profiles below the vegetation cover.** Landslide morphology and other subtle landform features can be better studied through digital terrain models produced by LiDAR.

*LIDAR stands for Light Detection and Ranging. Airborne LIDAR is a remote-sensing technology which, by sending out "laser beams" from aircrafts and detecting return signals, obtains the distance and hence elevation of objects. As shown in the figure, the beams can penetrate vegetation canopy and return signals from ground can be obtained providing high-resolution "bare" ground profiles that cannot be produced by traditional surveying methods.

### Debris Mobility Modelling

**Historical landslide data can be used to evaluate empirical damage zones.** Numerical modelling techniques using two-dimensional and three-dimensional methods have been routinely used for assessing the distribution, thickness and velocity of landslide debris.

# HOW are Natural Terrain Landslide Hazards Dealt with?

Typical ways to deal with natural terrain landslide hazards include avoidance, mitigation and stabilisation.

## Avoidance

Avoidance is the best approach. This is done **by restricting new developments in areas overlooked by steep hillsides or by providing suitable buffer areas** on the upslope side of the proposed development.

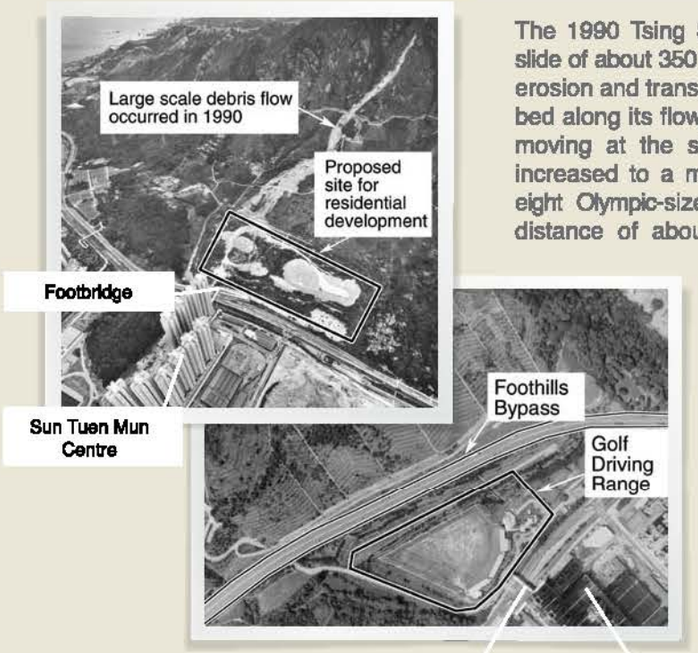
**The Government's strategy is to keep the risk within an "ALARP"* level with two key components: one for new and the other for existing developments. Mitigation measures can significantly reduce the consequences of landslides but may not be sufficient for rare, much larger events.**

For example in Hong Kong, for individual small house developments that are overlooked by sizeable, steep natural terrain, the need for natural terrain hazard study and mitigation would render the developments economically not viable. In such cases, alternative sites should be considered.

In addition, **risks and hence the cost for mitigation works can often be slashed by alternative means**, such as adjustment of the development layout, delineation of a no-build zone and simple drainage provisions.

* "ALARP" stands for As Low As Reasonably Practicable and is a risk management terminology. The GEO has adopted state-of-the-art quantitative risk assessment methodology in the management of landslide risk in Hong Kong. The principle of controlling landslide risk within the ALARP level is to attain a high level of slope safety that is practically achievable.

### Example of avoidance: Tuen Mun Area 19




The 1990 Tsing Shan debris flow started as a debris slide of about 350 m³ at the source. There was significant erosion and transportation of loose deposits on channel bed along its flow path. By the time the debris stopped moving at the slope toe, that volume involved had increased to a massive 20,000 m³ (or about the size of eight Olympic-sized swimming pools) with a run-out distance of about 1 km. Following this channelised debris flow, the original plan for a residential development at the Tsing Shan foothills was changed to a golf driving range to minimise risks. In 2000, another debris flow of about 1,600 m³ occurred at an adjacent drainage line, and resulted in debris being deposited on the golf driving range. This is a vivid reminder of the importance of proper land-use and development planning in containing in the landslide risk.



## Mitigation Works

Mitigation is preferred over stabilisation works for dealing with natural terrain landslide hazards since **it is often impractical, costly and environmentally undesirable to carry out extensive slope stabilisation works on large areas of natural terrain. Debris-resisting barriers, either rigid or flexible are common mitigation measures in Hong Kong.** Rigid barriers are designed for predicted debris impact force, while the design of flexible barriers with an energy rating is based on a semi-empirical approach. In some cases, baffles can be constructed upslope of the barriers to help dissipate the impact energy.

### Examples of mitigation measures

Gabion rigid barrier

Flexible barrier

Reinforced-Concrete rigid barrier

Concrete baffles

Rigid barriers at North Lantau

Rigid barriers at West Lantau

Rigid barriers and flexible barriers are to be used in different terrain and conditions:

- Rigid barriers have higher retention volume and debris resisting capacity. They are relatively more intrusive to environment and are suitable for use at drainage lines to mitigate risks of channelised debris flow.
- Flexible barriers have limited capacity and are relatively less intrusive to the environment. They are suitable for use in mitigating risks of boulder/rock fall, open hillslope landslide and small scale channelised debris flow and at locations where use of more substantial structures are not practical due to site constraints.

Flexible barriers at Bowen Road

Flexible barriers behind Shatin Hospital





## Overseas examples of mitigation measures

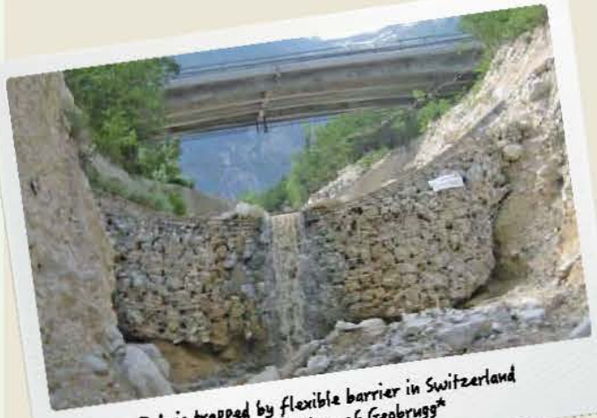
### Scotland (Europe)

"Exposure reduction" and "hazard reduction" are the two approaches adopted by Transport Scotland to manage landslide risk, with the former being the main focus. Exposure reduction involves public education, warning, precautionary signage and road closure; hazard reduction involves road realignment or engineering works.

A three-part management tool called "Detection-Notification-Action" is in place to reduce the exposure of road users to the risk of debris flow. Detection is carried out through monitoring of ground movement or landslide forecasting using real-time rainfall data. Appropriate authorities and parties are notified of the predicted or actual occurrence of landslides so that they can take immediate actions to mitigate the risk, such as road closure or traffic diversion.


*A "wig-wag" sign used in Scotland (in case of increased risk of a landslide, e.g. because of extensive rainfall, the sign flashes to warn road users) - From Transport Scotland website http://www.transportscotland.gov.uk*

Use of flexible barriers for mitigation of landslides in Scotland



Debris trapped by flexible barrier in Switzerland - Photo courtesy of Geobrugg*

### Switzerland (Europe)

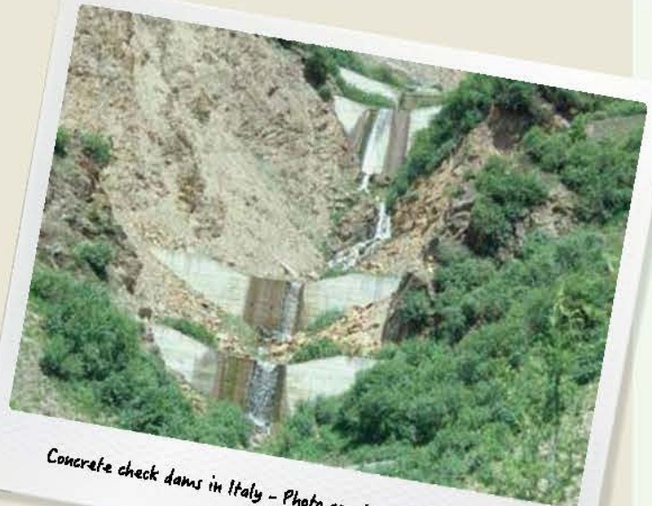
Switzerland has had some success in the use of flexible barriers in retaining debris flows. The typical barriers are generally up to 30 m wide and 6 m high. As the storage capacity of individual barriers is relatively limited, multiple barriers are usually needed.

Multiple flexible barriers in Switzerland - Photo courtesy of Geobrugg*

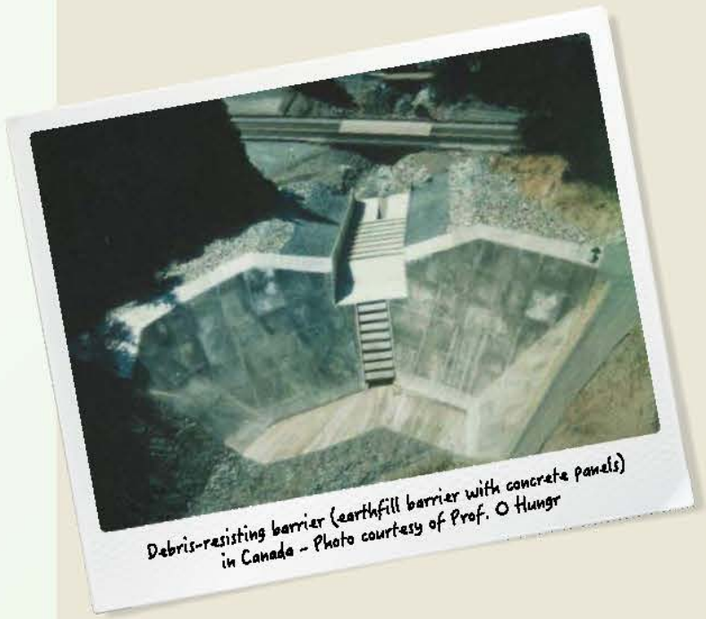
* From Geobrugg (2009). "Flexible Ring Net Barriers for Debris Flow Protection: The Economic Solution".

## Italy (Europe)

Debris flows are the most frequent type of catastrophic landslides in Italy, but rockfalls, rock slides and rock avalanches are also common. A variety of landslide prevention and mitigation works are used. Among these are debris-resisting barriers (including flexible and rigid barriers) and retention basins, adopted in areas where preventive measures are too expensive or cannot be used because of complex morphological conditions or other restrictions.



Concrete check dams in Italy – Photo courtesy of Prof. O Hungr



Debris-resisting barrier (earthfill barrier with concrete panels) in Canada – Photo courtesy of Prof. O Hungr

## Canada (North America)

Rockfalls pose frequent problems along transport routes through the mountainous terrain of Canada's western provinces. They have caused numerous deaths. Debris flows are a major problem in southern British Columbia where numerous defensive structures have been constructed to protect homes and routes. Debris-resisting barriers are prevalent in Canada, and are usually either earthfill embankments or earthfill dams covered by concrete or steel panels.





Overseas examples of mitigation measures

## Japan (Asia-Pacific)

A large number of landslides, including debris flows, shallow and deep-seated landslides, occur in Japan every year as a result of seasonal torrential rain, earthquakes and volcanic activity. To protect developments affected by landslide hazards, risk mitigation measures such as debris-straining structures, deflection structures, debris transport channels, check dams and debris-resisting barriers are commonly adopted.

Shield preventing debris from reaching a road in Japan

Debris-straining structure (grid structure) in Japan – Photo courtesy of Kobe Steel Limited

## Stabilisation Works

Under specific circumstances, **stabilisation measures at local areas can be an effective measure to prevent landslides on natural terrain.** For example, structural support in the form of soil nailing has been used to stabilise recent landslide scars and severely distressed hillsides. In-situ stabilisation measures such as rock bolts/dowels and concrete buttresses can be used to prevent localised rock and boulder falls.

### Examples of stabilisation measures

Soil nailing

Concrete buttress



2008 landslide at Shum Wat Road, Lantau Island

## Management of Natural Terrain Landslide Risk in Hong Kong

The Government's strategy on natural terrain landslide hazards is to keep the risk within an "ALARP" level with two key components: one for new and the other for existing developments.

## For New Developments

The aim here is to contain any undue increase in natural terrain landslide risk. This can be achieved through screening of land disposal and development proposals, judicious land-use and project planning to avoid hazardous areas, as well as repairing assessment and mitigation of any hazards for sites that could be affected by natural terrain hazards.

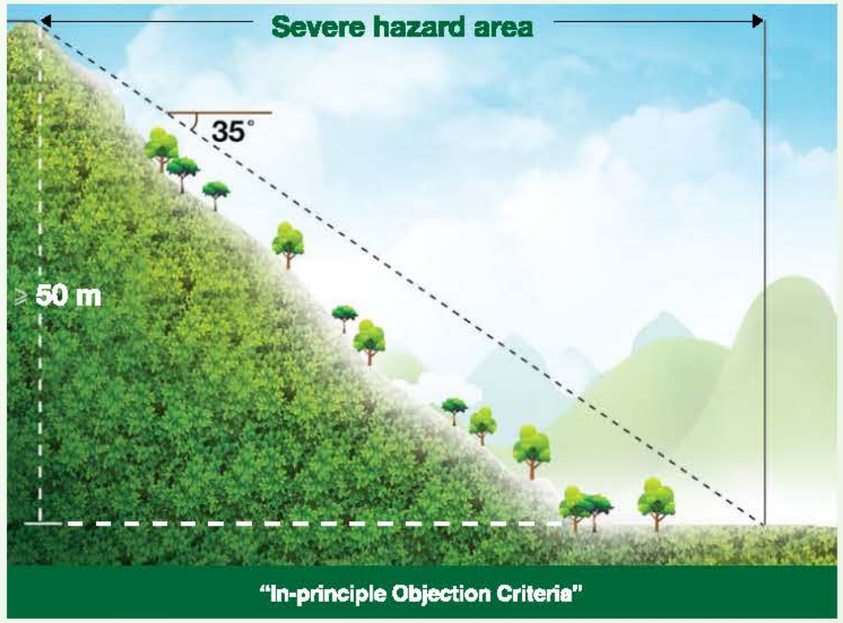
The GEO has established a set of simple "Inclusion" guidelines to assist planners, land administrators, and project managers to review whether or not a given site may require screening for natural terrain landslides hazards. The guidelines comprise the following two conditions:

| | |
|---|---|
| 1 | **The proposed development involves facilities with relatively high consequence-to-life (e.g. buildings, major infrastructures, densely-used playground, etc.).** |
| 2 | **There is a natural hillside sloping at more than 15° within 100 m horizontally upslope of the site.** |



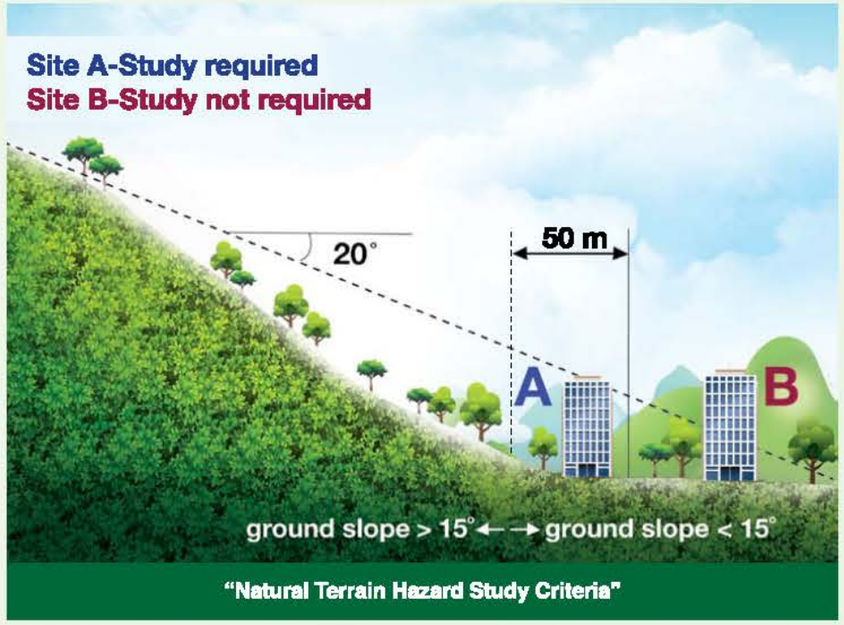
HOW

If a site meets these two conditions, the following technical criteria are used for screening the proposed development, based on a conservative estimation of the distance the landslide debris can reach.




"In-principle Objection Criteria"

**The "In-principle Objection Criteria" are aimed at identifying development sites that are faced with severe natural terrain hazards. Such hazards can affect the viability of the proposed development due to the potential requirement for implementing extensive and costly hazard mitigation works.**




"Natural Terrain Hazard Study Criteria"

**The "Alert Criteria" are aimed at identifying development sites that are susceptible to natural terrain hazards which entail a natural terrain hazard study (NTHS) and any necessary mitigation actions should be implemented as part of the development.**

## For Existing Developments

**"React-to-known-hazard" is the principle** that underlies the current approach for study and mitigation of natural terrain landslide risk for existing developments. It entails the following:

- **In case of an "immediate and obvious danger" situation, mitigation action should be taken urgently** – this situation would exist when the natural terrain shows signs of distress, continuing hazardous movement or incipient instability which would have jeopardized life or inflicted serious damage to property in the event of a landslide.

- **The natural terrain hazards should be studied where "there is reason to believe that a dangerous situation could develop", and mitigation actions should be taken when necessary.** For example, where persistent landslides on natural terrain have taken place in the past, and life and property may be in danger if further landslides occur. These cases are normally identified by the GEO through inspections of landslides, review of documentary records, and studies for safety clearance of squatters, etc.

The GEO has used quantitative risk assessment (QRA) to evaluate the risk levels of the HLCs and to devise a risk-based ranking system to prioritise systematic follow-up actions under the **Landslip Prevention and Mitigation Programme (LPMitP),** which commenced in 2010. Under the LPMitP, studies and necessary risk mitigation measures will be carried out each year for about 30 natural terrain catchments with known hazards to existing buildings or important transport corridors. Landscape treatments and/or soil bio-engineering measures will be provided to the hillsides as well as the mitigation measures as appropriate to minimise their visual impact and blend them with their surrounding environment.

The mitigation measures provided may not be sufficient to contain all the debris for rare but large-scale landslides. **Such measures nevertheless still help to reduce the impact and allow more time for escape or evacuation.**

Geotechnical engineers inspecting a flexible barrier under LPMitP



HOW

**Is maintenance required for natural terrain?**

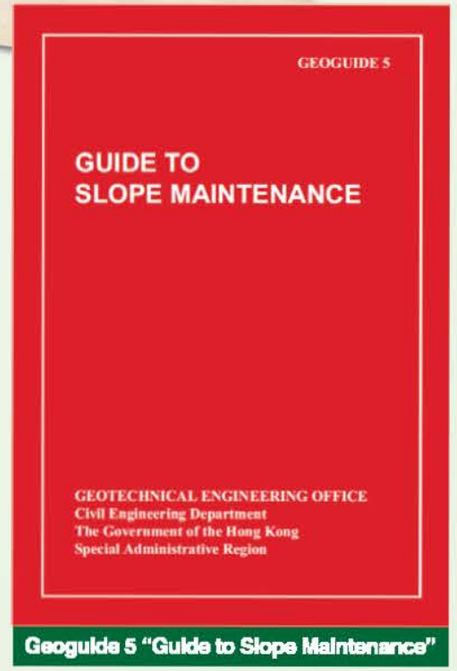
**Answer:**

Natural hillsides are generally covered by mature trees and vegetation and do not require maintenance. Where hazard mitigation measures are provided, the **physical integrity and continued functionality of the measures should be maintained.**

Where **unusual conditions or problems** arise, such as a rigid barrier filled up with a large amount of landslide debris, or significant movement observed at a boulder supported by a buttress, the maintenance party will need to **seek advice from a professionally-qualified geotechnical engineer.**

**Relevant guidelines are detailed in Geoguide 5 "Guide to Slope Maintenance".**

Rigid barriers protecting North Lantau Highway




Geoguide 5 "Guide to Slope Maintenance"

## Given Hong Kong's hilly terrain, is it possible to develop on natural terrain?

**Answer:**

As demand for housing continues, land formation on sloping ground would have to be considered for housing development.

If properly planned and designed (plus avoidance of vulnerable site), it is possible to develop on sloping natural terrain in a safe and cost-effective manner.

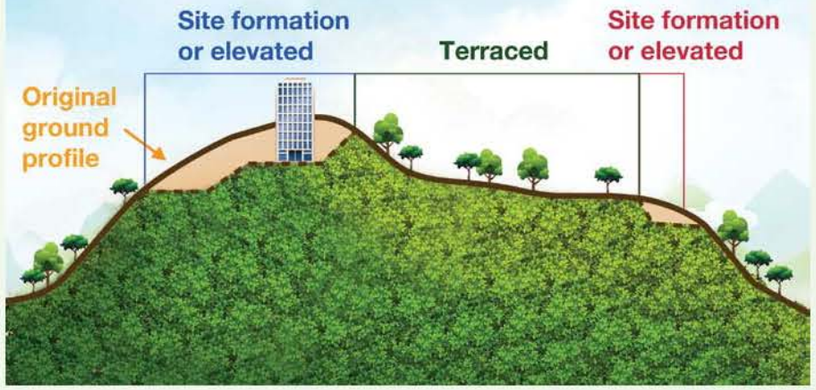
There are four typical development models on sloping terrain based on existing examples of local hillside development schemes (as shown below). Depending on the terrain conditions, a mix of these models can maximise the potential of the overall land platform formation on sloping ground.

### Building Platforms on Elevated Structures

Requires minimal site formation and has minimal limitations in the scale and location of individual sites, and can be developed for sites with significant geotechnical constraints.


### Hilltop Development

Requires removal of part of the upper portion of a hill with gentle to moderately steep terrain to form platforms on the truncated hilltop. It offers flexibility in the extent and layout of development within the site.

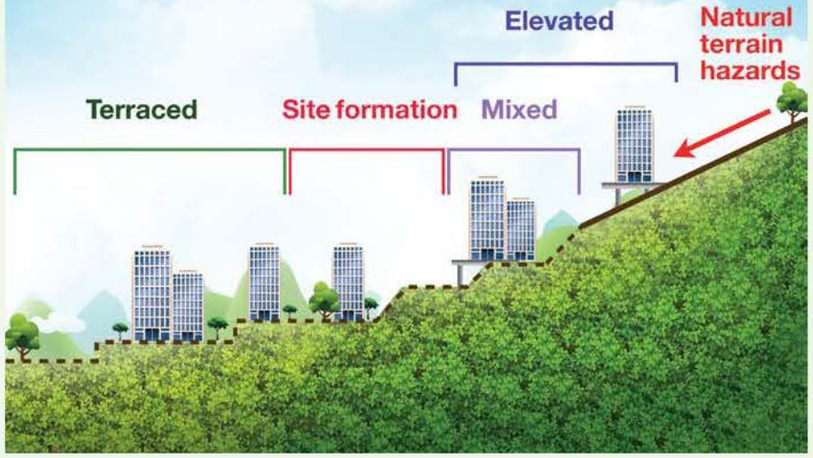





HOW

### Terraced Development

Requires transformation of a moderately steep hillside, up to about 15° gradient, into a series of terraced platforms. This involves extensive formation of man-made slopes and retaining walls.




### Major Open-cut Site Formation

Requires extensive cutting of hillsides and earth filling to form large building platforms downslope. This method with significant site-formation works may be considered in localised areas that are neither geotechnically nor environmentally sensitive.


Original ground profile

Ground profile after site formation

Excavated portion

# WHO should Act?

**Each & everyone of us!**


**Government's television announcement of public interest**

The natural terrain in Hong Kong is usually tranquil and the beauty of our natural landscape is for all of us to enjoy. However, **natural terrain landslide is a natural process and the associated risk can never be eliminated even with the mitigation measures.**

**Concerted efforts of the Government and the public are crucial in managing the landslide risk. In times of heavy rainfall and in particular, when landslip warning is in force, we should stay vigilant and keep away from slopes.**

Community involvement is more important than ever in response to an expected increase in the frequency and intensity of heavy rainfall resulting from climate change. The GEO has an ongoing public education programme and undertakes a wide range of outreaching activities to enhance public awareness of landslide risk and to build up community resilience to landslide events.

Public Talks

School Talks

"Meet the Public" Sessions

School exhibitions

The public should take heed of the Landslide Warning as almost all of the landslide fatalities in the past 20 years in Hong Kong occurred when the Landslip Warning was in force. **Many of these fatalities might have been avoided if the public had responded positively to our Landslip Warning messages.** When the Landslip Warning is in force, **the public should keep away from steep slopes.** People should in general cancel non-essential appointments and stay at home, or remain in a safe shelter and get familiarised with the personal precautionary measures below. The public should follow the Government's emergency response plans and leave promptly if asked to evacuate.


**"Keep Away From Slopes" poster showing precautionary measures to be taken by the public during heavy rain or landslip warning is in force**

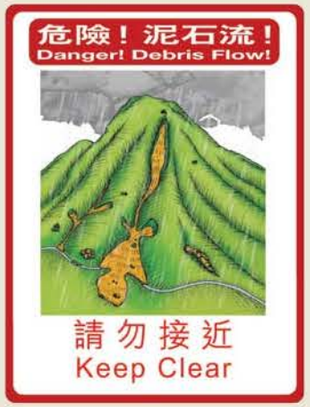
## The GEO Emergency Control Centre provides geotechnical advice to Government Departments on actions to be taken on landslides

The GEO maintains a 24-hour, year-round service to provide geotechnical advice to Government Departments on actions to be taken in case of danger arising from landslides. The service includes advice on closure of roads, evacuation of buildings, and urgent slope repair works. The primary objective of the emergency service is to protect the general public from landslide hazards and to assist Government Departments to restore services to the public, which have been disrupted by landslides.

Different types of warning signage are erected along busy roads with a history of landslides; in front of slopes affecting squatters; and near natural terrain landslide mitigation measures that are planned, under construction or completed. **The public should stay clear of these areas during heavy rainfall.**

## Landslip Warning Signs

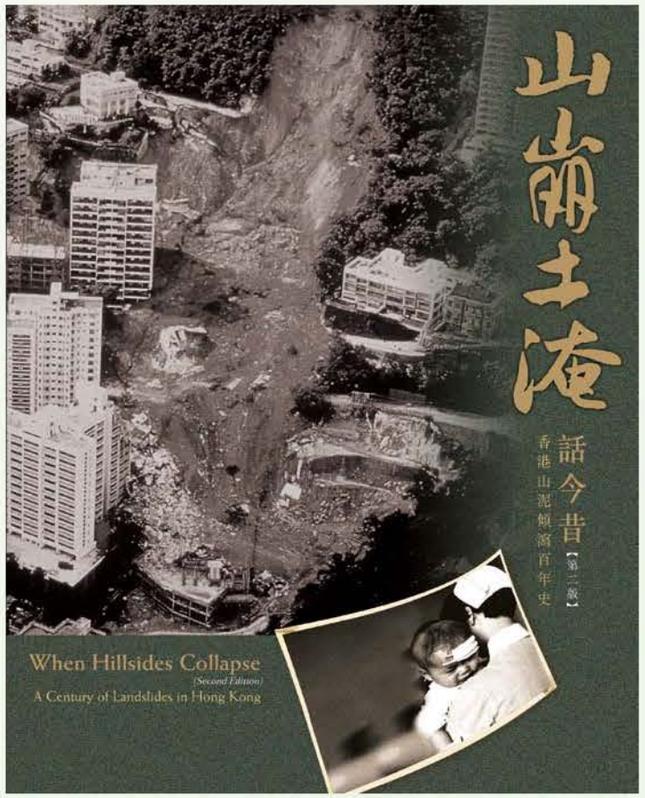





Note: For more information, please visit http://hkss.cedd.gov.hk/hkss/eng/landslip_sign.aspx



## Further Study




Our publication "When Hillsides Collapse – A Century of Landslides in Hong Kong" (2nd Edition) describes notable landside events in Hong Kong in chronological order from 1889 to 2008 with over 250 invaluable historical photographs.

The book is on sale at the Publications Sales Unit of Information Services Department (ISD) at HK$221. An electronic version is also available for downloading, please visit the following website for details: http://hkss.cedd.gov.hk/hkss/eng/when_hillsides_collapse_2nd.aspx.

## Further Information

Please also visit our CEDD website http://www.cedd.gov.hk/index.html, or our Hong Kong Slope Safety website http://hkss.cedd.gov.hk/hkss/eng/index.aspx for further information on slope safety in Hong Kong.

## Acknowledgements

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- Professor David Petley

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- Ir Dr Hon Lo Wai Kwok
- Dr Suzanne Lacasse
- Professor Oldrich Hungr
- Professor David Petley
- Dr Billy Hau



## Views on Hong Kong Natural Terrain Landslide Hazards

### Mr Michael Chugani
TV host and columnist

"Hong Kong's hilly terrain has always exposed it to the risk of landslides. Past landslides have shown the tragic circumstances they can cause. Most scientists now agree climate change is no longer just a talking point but a reality. Climate change brings extreme weather, and extreme weather can increase the risk of landslides. Awareness is the best guard against risk. As the saying goes, prevention is better than cure. Be aware, be safe. Knowing the risks of landslides can keep you and your family safe."

### Dr Suzanne Lacasse
Technical Director of the Norwegian Geotechnical Institute, Norway

"Landslides will occur, but they turn into disaster most often because people are not prepared well enough for how to react and how to handle what is happening. GEO cannot solve the landslide problem alone, the public has to be proactive and to be prepared to help the Government to do this."

### Professor Oldrich Hungr
Professor of Engineering Geology at the University of British Columbia, Canada

"Hong Kong is unique for steep terrain, deep weathering, high rainfall and high population. As a result, protection of human life against landslide is significant. Hong Kong has a world-class institute of slope safety. But we should not take that as a proof that we have defeated the landslide "dragon". Hong Kong has ever increasing population and its development is coming closer to the steep slopes, while rainfall intensity is increasing. Hong Kong must keep up the good work in case the sleeping landslide "dragon" would wake up one day."

### Professor David Petley
Pro-Vice-Chancellor of the University of East Anglia, United Kingdom

"Asia is one of the most landslide prone areas in the world. It is an extremely challenging work to reduce the loss of lives to landslide and GEO is famous around the world for doing this. Landslide is very sensitive to heavy rainfall. With climate change and the increasing trend of heaviest rainfall, Hong Kong people will need to be mindful of the danger of slope and to pay attention to the warning of evacuation and orders from the Government that may go out during extreme rainfall event."

### Dr Billy Hau
Principal Lecturer, School of Biological Sciences,
The University of Hong Kong; Vice-chairman, the Conservancy Association

"It has been widely recognised that the world's climate is changing. The Hong Kong Observatory has predicted that heavy rainstorms will become more frequent in future. Despite the efforts put by CEDD in fixing the slopes in Hong Kong, landslide risk is still high in view of the changing climate. We should not underestimate the need to improve the safety of slopes in Hong Kong, especially those on natural terrains."

To be continued on back cover

# NATURAL TERRAIN LANDSLIDE HAZARDS IN HONG KONG

**Geotechnical Engineering Office**
**Civil Engineering and**
**Development Department**

**Professor Joseph Sung**
Vice Chancellor, the Chinese University of Hong Kong

"The Hong Kong Observatory has predicted that climate change is likely to increase both the frequency and intensity of extreme rainfall. There is therefore an increasing chance of extreme weather that could cause serious landslide disasters. It is imperative that citizens remain highly vigilant about landslides and be prepared to deal with extreme weather events."

**Ms Liza Wang**
Singer and actress

"Although landslides arising from extreme weather cannot be precluded, the concerted effort of the Government and the general public could enhance our resilience against landslide disasters and reduce loss of life and damage to property to the lowest possible level."

**Hon Ip Kin Yuen**
Legislative Council Member

"In recent years, extreme weather has brought about many disasters worldwide, causing significant casualties and economic losses. Given its hilly terrain and densely populated development, there is a high risk that serious landslides on natural terrain may occur should Hong Kong be hit by an extreme rainfall. The GEO has been using international best practice and state-of-the-art technology in mitigating such natural terrain landslide risk."

**Ir Dr Hon Lo Wai Kwok**
Legislative Council Member

"The Hong Kong Slope Safety System is world-acclaimed and has successfully brought about a significant reduction in landslide risk in Hong Kong. However, given Hong Kong's climate, hilly terrain, dense population and continuing development, there is still landslide risk posed by man-made slopes and also from natural hillsides. Therefore, the Government is sustaining its efforts on improving slope safety and the inclusion of natural hillsides for action in the "Landslip Prevention and Mitigation Programme" is a right and forward-looking decision."