Words into Action Guidelines:
National Disaster Risk Assessment
Hazard Specific Risk Assessment

4. Landslide Hazard and Risk Assessment

Key words:
landslide, landslide hazard, landslide vulnerability, landslide hazard map, risk management

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The term "landslide" refers to a variety of processes that result in the downward and outward movement of slope-forming materials, including rock, soil, artificial fill, or a combination of these. The materials may move by falling, toppling, sliding, spreading, or flowing. The schematics in figure 1 illustrate the major types of landslide movement.

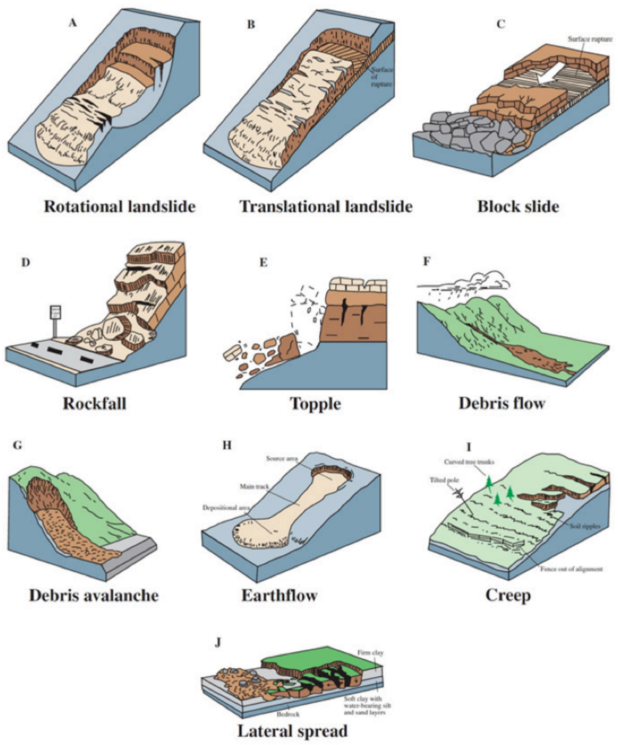

Figure 1 - Schematics illustrating the major types of landslide movement[1].

In many parts of the world, landslides are a frequent natural hazard and a major threat to humans and the environment. According to the International Disaster Database of the Centre for Research on the Epidemiology of Disasters (CRED) (EM-DAT)[2], since 1900 some 130,000 persons have lost their lives because of landslides and flash floods; and the economic losses amounted to over US$ 50 billion. In the period from 2000 to 2014, the corresponding figures were around 26,000 deaths and US$ 40 billion in losses. The actual figures are, however, much higher.

In the CRED-EM database, the losses due to earthquake-triggered landslides are attributed to earthquakes, and many landslide events with no casualties, but significant material losses are not reported. For example, 20-25 per cent

1 United States Geological Survey (2004). Landslide types and processes. Fact sheet 2004-3072. Available from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html

2 Guha-Sapir, D., R. Below and P. Hoyois. The CRED/OFDA *International Disaster Database*. Université catholique de Louvain. Belgium.

of the 87,000 casualties (69,000 confirmed killed and 18,000 missing) caused by the Sichuan (or Wenchuan) Earthquake of 12 May 2008 were the result of the landslides triggered by that event.[3] Recent catastrophic landslides in Afghanistan, United States, the Philippines and India illustrate that landslides are still a major threat in developed as well as developing countries.

The volume of soil and rock mobilized in a landslide can vary from a small individual boulder to millions, and in rare cases billions, of cubic metres. Generally, the potential destructiveness of a landslide is a function of the volume of the masses that are mobilized, and their velocity. But even a single boulder can cause several fatalities.

Sources and setting

The primary driving factor of landslides is gravity acting on a portion of a slope that is out of equilibrium. The following are some of the major landslide triggering mechanisms:

- River erosions, glaciers, or ocean waves
- Weakening of rock and soil slope proprieties through water saturation by snowmelt or heavy rains
- Stresses, strains and excess of pore pressures induced by the inertial forces during an earthquake (earthquakes of magnitude greater than or equal to 4.0 can trigger landslides)
- Volcanic eruptions with the production of loose ash deposits that may become debris flows (known as lahars) during heavy rains
- Stockpiling of rock or ore, from waste piles, or from man-made structures
- Changes of the natural topography caused by human activity.

3 Zhang, L.M., S. Zhang and R.Q. Huang (2014). Multi-hazard scenarios and consequences in Beichuan, China: the first five years after the 2008 Wenchuan earthquake. *Engineering Geology*, vol.180, pp. 4-20.

Landslide hazard assessment

Landslide hazard is a function of susceptibility (spatial propensity to landslide activity) and temporal frequency of landslide triggers, and its assessment may be done on local (individual slope), regional, national, continental, or even global scales. The most appropriate method in each scale depends on the extent of the study area and on the available data. Examples of various methodologies for landslide hazard assessment on different scales can be found in the literature.[4,5,6,7]

In any type of landslide hazard assessment, there is a need to consider topography and other factors that influence the propensity to landslide activity (susceptibility factors), as well as landslide triggering factors (precipitation, earthquakes, human activity). Table 1 lists the input data typically required for landslide hazard assessment at regional to national scales.

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4 Nadim, F. and others (2006). Global landslide and avalanche hotspots. *Landslides*, vol. 3, issue 2, pp. 159-173.

5 Nadim, F., H. Einstein and W.J. Roberts (2005). Probabilistic stability analysis for individual slopes in soil and rock. *Proceedings of the International Conference on Landslide Risk Management.*

6 Norwegian Geotechnical Institute (2010). SafeLand project. *Overview of landslide hazard and risk assessment practices.*

7 Corominas, J. and others (2014). Recommendations for the quantitative analysis of landslide risk. *Bulletin of Engineering Geology and the Environment,* vol. 73, issue 2, pp. 209-263.

Description of input data	National entities that most commonly have this data	Examples of open databases available from international sources
Digital elevation model	National mapping and cartography authority	SRTM30 (NASA)
Lithology	National geological survey	UNESCO (CGMW, 2000), One Geology initiative
Vegetation cover	National agriculture/ environment and/or national forest agency	GLC2000 database
Soil moisture factor	National agriculture/ environment and/or national meteorological agency	Climate Prediction Center
Hourly, daily and monthly precipitation	National meteorological agency	Global Precipitation Climatology Centre of the German National Meteorological Service, DWD
Seismicity	National building code(s)	Global Seismic Hazard Program, Global Earthquake Model
Infrastructure and road/railway network in mountainous regions	National road and/or railway authority	Google maps

Table 1 - Sources of data for landslide risk assessments at regional and national scale

There are many sources and types of uncertainty in landslide hazard assessment. By far the main source of uncertainty is the epistemic uncertainty related to our limited knowledge about the materials that make up the slope(s), their response under various external perturbations, and the characteristics of the triggering factors.

Soils, rocks and other geomaterials exhibit significant spatial variability (aleatory uncertainty) and their properties often change markedly over small distances. Many non-local scale landslide hazard assessment models are empirical and should be calibrated/validated with regional and/or national database(s) of previous landslide events. Landslide inventory maps are often an important input for the landslide susceptibility/hazard assessment and/or validation.

However, even in developed countries, the databases of landslide events are usually far from complete. Often they only cover the events from the recent past, and/or have an over-representation of landslides triggered by a single extreme event, and/or are heavily biased towards the events reported by a single source, such as the national road or rail authority.

Climate change increases the susceptibility of surface soil to instability because of abandoned agricultural areas, deforestation and other land-cover modifications. Anthropogenic activities and uncontrolled land-use are other important factors that amplify the uncertainty in landslide hazard assessment.

Exposure and vulnerability assessment

Exposure of the population and/or the built environment to landslide risk can be assessed by superimposing landslide hazard map(s) on maps of population density, the built environment and infrastructure. However, this type of assessment provides only a qualitative picture of the exposure. Landslides vulnerability assessment is a complex process that should consider multiple dimensions and aspects, including both physical and socioeconomic factors. Physical vulnerability of buildings and infrastructure is a function of the intensity of the landslide event and the resistance levels of the exposed elements.[8,9,10,11,12,13]

Societal vulnerability and resilience of a community, on the other hand, are related to factors such as demographics, preparedness levels, memory of past events, and institutional and non-institutional capacity for handling natural hazards. Although a significant amount of literature exists[14] on the assessment of societal vulnerability to natural hazards, few studies specifically address the social and economic vulnerability to landslides.

In the SafeLand project, an indicator-based methodology was developed to assess the (relative) societal vulnerability levels. The indicators represent the underlying factors that influence a community's ability to deal with and recover from the damage associated with landslides.[15,16] The proposed

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8 Uzielli, M. and others (2008). A conceptual framework for quantitative estimation of physical vulnerability to landslides. *Engineering Geology,* vol.102, issues 3-4, pp. 251-256.

9 Norwegian Geotechnical Institute (2011). SafeLand project. *Physical vulnerability of elements at risk to landslides: methodology for evaluation, fragility curves and damage states for buildings and lifelines.*

10 ___________ Case studies of environmental and societal impact of landslides – Part A: Rev. 1. Case studies for environmental (physical) vulnerability.

11 Papathoma-Köhle, M. (2016). Vulnerability curves vs. vulnerability indicators: application of an indicator-based methodology for debris-flow hazards. *Natural Hazards and Earth System Sciences*, vol. 16, pp. 1771-1790.

12 Eidsvig, U.M.K. and others (2014). Quantification of model uncertainty in debris flow vulnerability assessment. *Engineering Geology*, vol. 181, pp.15-26.

13 Winter, M.G. and others (2014). An expert judgement approach to determining the physical vulnerability of roads to debris flow. *Bulletin of Engineering Geology and the Environment,* vol. 73, issue 2, pp. 291-305.

14 Cutter, S., J. Boruff and L. Shirley (2003). Social vulnerability to environmental hazards. *Social Science Quarterly,* vol. 84, issue 2, pp. 242-261.

15 Norwegian Geotechnical Institute (2012). SafeLand project. M*ethodology for evaluation of the socio-economic impact of landslides (socio-economic vulnerability)*.

16 Eidsvig, U.M.K. and others (2014). Assessment of socioeconomic vulnerability to landslides using an indicator-based approach: methodology and case studies. *Bulletin of Engineering Geology and the Environment,* vol. 73, issue 2, pp. 307-324.

methodology includes indicators that represent demographic, economic and social characteristics such as the human development index and gross domestic product, and indicators representing the degree of preparedness and recovery capacity. The purpose of the societal vulnerability assessment is to set priorities, serve as background for action, raise awareness, analyse trends and empower risk management.

Risk assessment use in national DRR measures

Studies on global distribution of landslide hazard,[17] as well as detailed assessment of the reported occurrence of landslide disasters in the CRED-EM database, suggest that the most exposed countries to landslide risk are located in south Asia, along the Himalayan belt, in east Asia, south-eastern Asia, and in Central and South America.

In most developed countries with high landslide hazard, landslide events rarely end up as disasters. This is mainly due to the low exposure in the most landslide-prone areas, as well as the increasing ability to identify the landslide-prone areas and to implement appropriate landslide risk management actions.

Many countries that have areas with high landslide hazard lack the necessary legislation and regulations to prioritize and implement a landslide risk mitigation plan. Often it is asserted that it "takes a disaster to get a policy response", and case studies of landslide risk management in different countries show a relationship between the incidence of disasters, and progress and shifts in landslide risk management.[18]

Disasters can catalyse moments of change in risk management aims, policy and practice. Increasingly, the decision-making processes of the authorities in charge of reducing the risk of landslides and other hazards are moving from "expert" decisions to include the public and other stakeholders.[19]

In practice, effective landslide risk mitigation should be implemented at local (individual slope) or regional level. On the local scale, the design of a risk mitigation measure, for example an early warning system, can be based on a number of reasonable scenarios and may involve the following steps:

- Define scenarios for triggering the landslide(s) and evaluate their probability of occurrence

17 Nadim, F. and others (2012). *Assessment of Global Landslide Hazard Hotspots*. Berlin and Heidelberg: Springer.

18 Norwegian Geotechnical Institute (2011). SafeLand project. *Five scoping studies of the policy issues, political culture and stakeholder views in the selected case study sites – description of methodology and comparative synthesis report.*

19 Scolobig, A., M. Thompson and J. Linnerooth-Bayer (2016). Compromise not consensus: designing a participatory process for landslide risk mitigation. *Natural Hazards,* vol. 81, supplement 1, pp. 45-68.

- Estimate the volume and extent of the landslide and compute the run-out distance for each scenario
- Estimate the losses for all elements at risk for each scenario
- Compare the estimated risk with risk acceptance/risk tolerance criteria
- Implement appropriate risk mitigation measures if required.

It is not clear that this level of rigour is always practised in landslide risk management, especially in poor countries where resources are limited.

Good practice of landslide risk management

One of the best examples of good landslide risk management practice is found in Hong Kong, China. Hong Kong is situated on the south-eastern coast of China, has a subtropical climate with an average annual rainfall of 2,300 mm, peaking in the summer, with regular rainfall events of intensities exceeding 100 mm/hour.

Hong Kong has a small land area of about 1,100 km2, over 60 per cent of which is located on hilly terrain. Its population has increased steadily from 2 million in 1950 to over 7 million today. This has led to a huge demand for land for residential use and infrastructure, and resulted in a substantial portion of urban development located on or close to man-made slopes and natural hillsides. Man-made slopes that are not properly designed and steep hillsides are susceptible to landslides during heavy rainfall, and debris flows are common in natural terrain. As a result, landslides are a large natural hazard in Hong Kong, where they can cause significant casualties and socioeconomic impacts.

On 18 June 1972, after days of heavy rainfall, two destructive landslides in Sau Mau Ping and at Po Shan Road in Hong Kong killed one hundred and thirty-eight people, covered a resettlement area with landslide debris and caused a high-rise building to collapse. In 1977, in the aftermath of these and other fatal landslide disasters, the Geotechnical Control Office (now the Geotechnical Engineering Office (GEO)) was set up to strategically implement a comprehensive system to maintain slope safety.

The Slope Safety System it developed comprises several initiatives to reduce landslide risk in a holistic manner. The key components of the system are comprehensive enforcement of geotechnical standards, community participation for slope safety, systems for early warning and emergency response, and comprehensive databases of landslide events and implemented risk mitigation measures. Several studies show that the implementation of the Slope Safety System has reduced the annual fatalities due to landslides by over 50 per cent since the late 1970s.[20] There have now been no fatalities in almost a decade.

Programmes that have achieved this level of success are rare and are obtained at considerable cost. In developing countries, few, if any, examples exist of successful countrywide reduction in landslide losses as a result of such initiatives. Landslides are among the most potentially manageable of all natural hazards, given the range of approaches and techniques that are available to reduce the level of hazard. There is much scope to reduce their impacts.

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20 Malone, A.W. (1997). *Risk Management and Slope Safety in Hong Kong*. The Hong Kong Institution of Engineers.

Resources for further information

The following sources provide useful information and tools for landslide hazard and risk assessment, and landslide risk management:

- European Commission FP7 Project SafeLand[21]
- Geological Survey of Canada landslide guidelines[22]
- International Consortium on Landslides[23]
- United States Geological Survey landslide hazards programme[24]
- Geotechnical Engineering Office, Hong Kong slope safety[25]
- UNISDR global assessment reports on disaster risk reduction[26]
- MoSSaiC: Management of slope stability in communities[27]

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21Norwegian Geotechnical Institute (2012). SafeLand project. R&D program Safeland. Abstract available from www.ngi.no/eng/Projects/SafeLand

22 Government of Canada (2017). Hazards: Landslides. Available from www.nrcan.gc.ca/hazards/landslides

23International Consortium on Landslides. Available from http://icl.iplhq.org/category/home-icl/

24 Landslide Hazards Program. Available from http://landslides.usgs.gov/

25 Geotechnical Engineering Office (2012). Hong Kong Slope Safety. Available from http://hkss.cedd.gov.hk/hkss/eng/index.aspx

26 United Nations Office for Disaster Reduction (2015). Global Assessment Report. Available from www.preventionweb.net/english/hyogo/gar/

27 Anderson, M. and L. Holcombe. Management of Slope Stability in Communities. Available from www.bristol.ac.uk/geography/research/hydrology/research/slope/mossiac/