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LANDSLIDE RISK EVALUATION

Canadian Technical Guidelines and Best Practices related to Landslides: a national initiative for loss reduction

M. Porter and N. Morgenstern

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Canadian Technical Guidelines and Best Practices related to Landslides: a national initiative for loss reduction

LANDSLIDE RISK EVALUATION

Note to Reader

This is the seventh in a series of Geological Survey of Canada Open Files that will be published over the next several months. The series forms the basis of the *Canadian Technical Guidelines and Best Practices related to Landslides: a national initiative for loss reduction.* Once all Open Files have been published, they will be compiled, updated and published as a GSC Bulletin. The intent is to have each Open File in the series correspond to a chapter in the Bulletin.

Comments on this Open File, or any of the Open Files in this series, should be sent before the end of March 2013 to Dr. P. Bobrowsky, pbobrows@NRCan.gc.ca

1. INTRODUCTION

Landslide risk evaluation compares landslide risks, as determined from the risk analysis, against risk tolerance or risk acceptance criteria to guide the design and approval of proposed development and to prioritize treatment and monitoring efforts for existing development that is or could be exposed to a landslide (Figure 1, VanDine, 2012, and reproduced below). In situations where consequences are not considered, the process is technically *hazard evaluation*, but for simplicity, in this paper the term *risk evaluation* is used throughout. Landslide risk tolerance and risk acceptance criteria are more broadly referred to as landslide safety criteria. The combined process of risk identification, risk analysis and risk evaluation is referred to as risk assessment.

The risk evaluation approach used and the landslide safety criteria adopted can vary depending on the risk scenario (sequence of events with an associated likelihood or probability of occurrence and consequences), the applicable legal framework, regulations and standards of practice and, for governments and corporations, factors such as market capitalization and insurance coverage that can influence the level of risk that can be tolerated or accepted.

This contribution focuses on general principles and approaches of evaluating different measures of landslide risk. The attention is on the evaluation of landslide risk associated with existing and proposed residential development, because it is here that national guidelines can prove most beneficial. Many of the concepts and techniques applied to landslide risk evaluation for residential development can also be applied to other elements at risk (objects or assets such as human health and safety, property, aspects of the environment and/or financial interests that could be adversely affected by a landslide). Many of the examples provided involve sub-aerial landslides, but the risk evaluation concepts can also be applied to submarine landslides and landslide-generated waves.

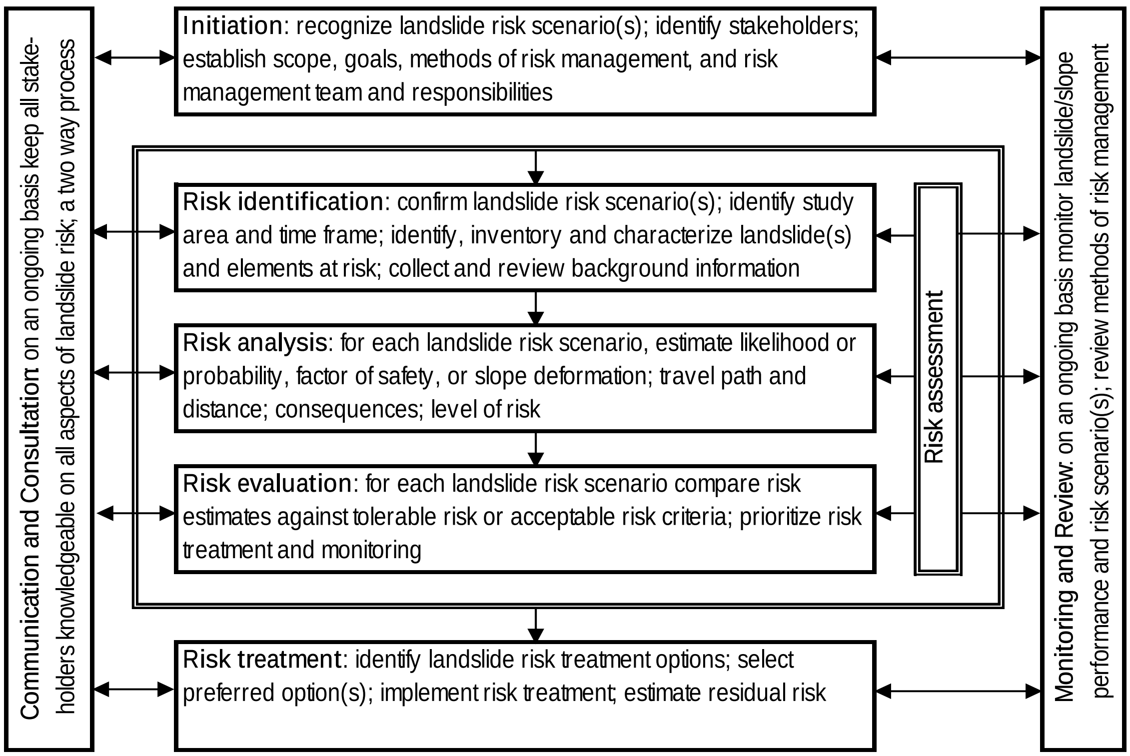

Figure 1: Landslide Risk Management Process (from VanDine, 2012; adapted from ISO, 2009)

Approving authorities across Canada frequently review the results of landslide risk assessments as part of the submissions for development and/or building permits. In such assessment reports, landslide professionals are often required to use a statement similar to *the land may be used safely for the use intended*, but rarely has *safe* been actually defined by the approving authority. Some improvements have been made in this regard, such as those documented in the Association of Professional Engineers and Geoscientists of British Columbia's landslide guidelines (APEGBC, 2010), but provincial and national approaches to risk evaluation and landslide safety criteria are typically lacking. Landslide safety criteria from jurisdictions across Canada and internationally are reviewed and the potential benefits of establishing provincial and/or national criteria are discussed. Considerations for communicating and consulting on landslide safety criteria and the results of risk evaluations are provided herein.

Because risk evaluation is a rapidly evolving topic in Canada, this contribution should be treated as a 'work in progress' and updates will likely be required as Canadian approaches and landslide safety criteria evolve.

2. GENERAL PRINCIPLES

2.1 Individual versus Societal Risk

Where rapid landslides are possible, the potential for loss of life typically represents the overriding consequence of concern to authorities charged with approving proposed developments above, on or below landslide prone terrain. Safety criteria based on the risk of loss of life guide the development approval process for landslide prone areas such as in Hong Kong, Australia, and recently in the District of North Vancouver, BC, and, although not specific to landslides, form part of industrial health and safety regulations in the United Kingdom and the Netherlands (AGS (Australian Geomechanics Society), 2000; AGS, 2007; Ale, 2005; Leroi et al., 2005; Whittingham, 2009). Two measures of risk are considered: risks to individuals and risks to groups (or societal risk).

Individual risk addresses the safety of individuals who are most at risk in an existing or proposed development. Societal risk addresses the potential societal losses as a whole caused by total potential losses of people in the community from a hazard event. When considering the exposure to a single landslide, risk is calculated according to Equation 1:

$$R = P_H * P_{S:H} * P_{T:S} * V * E \qquad [1]$$

where:
R = risk;
P_H = annual probability of the hazard (i.e. landslide) occurring;
$P_{S:H}$ = spatial probability that the landslide will reach the individual;
$P_{T:S}$ = temporal probability that the individual will be present when the landslide occurs;
V = the vulnerability, or probability of loss of life if an individual is impacted; and
E = the number of people at risk; equal to 1 for individual risk.

Partial risk is the combination of the first two terms, $P_H * P_{S:H}$. Partial risk is also known as encounter probability.

Where risk of loss of life criteria are used in countries with a common law (case law or precedent) legal system, the maximum tolerable level of risk for a new development is typically 1:100,000 per annum for the individual most at risk (Leroi et al., 2005). A distinction is often made between new and existing development, with individual risks as high as 1:10,000 per annum sometimes tolerated for existing development.

When the area of a potential landslide is small and the density of development is low, approval decisions are typically governed by the estimated individual risk. In contrast, when large groups are exposed to a potential landslide, societal risk analysis is typically used. For societal risk, if the spatial and temporal probabilities and the vulnerability vary across the population exposed to the hazard, the group is subdivided according to uniform levels of exposure with the results then summed to arrive at a total expected number of fatalities from the potential landslide.

Societal risk estimates are typically presented on graphs showing the expected frequency of occurrence and cumulative number of fatalities, referred to as F-N curves (Figure 2 is one example). F-N curves were originally developed for nuclear hazards and the aerospace industries (Kendall et al., 1977) to illustrate thresholds that reflect societal aversion to multiple fatalities during a single catastrophic event. The graph is subdivided into four areas: *unacceptable risk;* tolerable risk that should be reduced further if practicable according to the *as low as reasonably practicable* (ALARP) principle; *broadly acceptable risk*; and a region of very low probability but with the potential for >1000 fatalities that require *intense scrutiny*. From the perspective of potential loss of life from a landslide, development is typically approved if it can be demonstrated that the landslide risk falls in the ALARP or broadly acceptable regions on an F-N curve (Kendall et al., 1977).

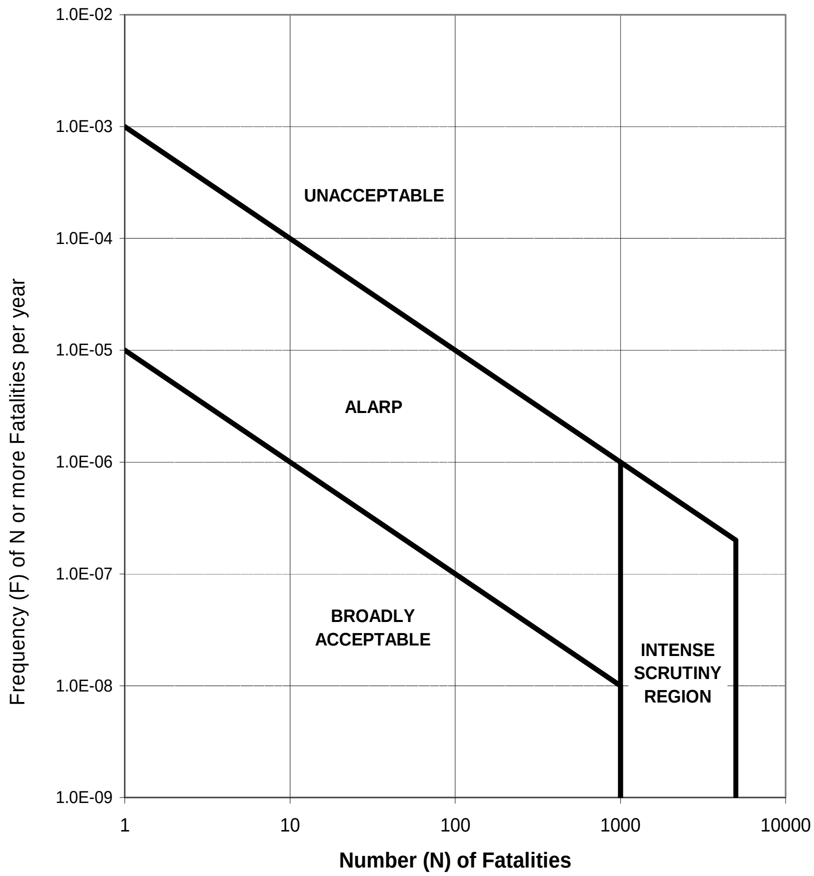

Figure 2. Example F-N Curve for Evaluating Societal Risk.

2.2 Consultation Zone

The geographic area considered for a landslide risk assessment is known as the *consultation zone* (Geotechnical Engineering Office, 1998): *a zone of standard extent that includes the area of proposed development within the maximum credible extent of potential landslides* (Hungr and Wong, 2007). In Hong Kong, for example, assessments for potential rock fall, typically corresponds to a 500 m wide strip of land along the base of a slope. Altering the size of the consultation zone can change the estimates of societal risk.

The above definition is effective for proposed or existing development in an area that is the responsibility of a single approving authority, but otherwise has its limitations. A more inclusive definition is proposed (Porter et al., 2009). The consultation zone is: *a zone that includes existing and proposed development in one or more jurisdictional areas, that contains the largest credible area potentially affected by one or more concurrent landslides.*

Determining the largest credible area potentially affected by landslides requires an inventory of past landslides, an estimation of landslide volume, area or discharge and frequency, and a landslide runout analysis. In some cases, a preliminary estimate of the consultation zone can be made based on the area of the landform: for example, talus slopes affected by rock falls and creek fans subject to debris flows are typically well defined. Such information may not be known at the outset of a risk assessment unless regional landslide studies have been carried out and the resulting maps prepared.

2.3 Voluntary and Involuntary Risk

Individuals and organizations are typically willing to accept greater *voluntary* risks, that is, risks that are perceived to be within their control. Examples include an individual's risk of fatality from smoking (1:200 per annum), canoeing (1:500 per annum) and driving (1:10,000 per annum) (Whittingham, 2008). Residential occupants, however, rarely consider landslide risks as voluntary. Such landslide risks are typically considered *involuntary,* and thus landslide safety criteria values are likely to be less than the values reported earlier.

Risks to workers from landslides might be considered voluntary because employees know that benefits (income) are, at least, partial compensation for the perceived risks, provided the risks are adequately understood and communicated. For example, Bunce and Martin (2011) suggest that a risk of fatality of 1:10,000 per annum represents a reasonable target for train crews operating in landslide prone terrain.

2.4 Tolerable versus Acceptable Risk

The following definitions are modified from VanDine (2012):

- *tolerable risk:* risk within a range that society or an individual can live with so as to secure certain net benefits; a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible (adapted from AGS, 2007); and
- *acceptable risk:* risk that society or an individual is prepared to accept and for which no further risk reduction is required (adapted from AGS, 2007).

The use of risk of loss of life criteria originated in the United Kingdom and the Netherlands during the 1970s and 1980s in response to the need to manage risks from major industrial accidents (Ale, 2005). Hong Kong adapted the United Kingdom criteria for the management of landslide risks, and similar approaches have been applied in Australia (AGS 2007).

While landslide safety criteria may vary amongst jurisdictions and the criteria for individual and societal risk are different, some common general principles apply (Leroi et al., 2005):

- the risk from a landslide to an individual should not be significant when compared to other risks to which a person is exposed in everyday life;
- the risk from a landslide should be reduced wherever reasonably practicable; that is, the ALARP principle should apply;
- if the potential number of lives lost from a landslide is high, the corresponding likelihood that the landslide will occur should be low; this accounts for society's intolerance to many simultaneous casualties, and is embodied in societal landslide safety criteria; and,
- higher risks are likely to be tolerated or accepted for existing developments than for proposed developments.

In the United Kingdom, the maximum tolerable risk to an individual from an industrial accident in a new development has been set by the Health and Safety Executive at 1:100,000 per annum. The maximum tolerable risk for workers, based on the assumption that the risk faced by workers is somewhat voluntary, has been set at 1:1,000 per annum (Whittingham, 2008).

In the Netherlands, maximum acceptable risk to an individual in a new development is 1:1,000,000 per annum. In practice, however, Ale (2005) has shown that the United Kingdom and Netherlands risk tolerance criteria are very similar as a result of the different legal systems employed by the two countries and mandatory application of the ALARP principle in the U.K.

2.5 Mortality Rates and Risks in Everyday Life

While there is precedent for using F-N curves and maximum tolerable risk criteria for individuals to evaluate landslides risks in Hong Kong and Australia, is it appropriate to apply similar tolerable risk criteria in Canada? A comparison of the Hong Kong landslide risk tolerance criteria against Canadians' level of background risk suggests these criteria may in fact be appropriate.

An individual's annual risk of loss of life depends on a number of factors including his/her age, occupation, general state of health and other environmental factors. The Government of Canada (Canada, StatsCan, 2005) reports the average Canadian mortality rates by cause. Between 2000 and 2005, the age-standardized risk of loss of life by all causes was approximately 1:175 per annum, the average risk from accidental causes was about 1:2,500 per annum, and the average risk from automobile accidents was about 1:10,000 per annum.

Table 1 compares the increase in the average Canadian's risk of loss of life if exposed to various levels of landslide risk. As discussed earlier, a general principle in establishing landslide safety criteria is that the incremental risk from a landslide should not be significant when compared to other risks in everyday life. Although *significant* is not defined (Leroi et al., 2005), an analysis of the increase in risk from various levels of landslide exposure suggests that the increase is <0.2% (low) for landslide risk levels less than 1:100,000 per annum.

Table 1. Canadians' Incremental Risk of Loss of Life (per annum) under various Landslide Risk Levels (after Canada, StatsCan, 2005).

Landslide risk per annum (expressed in a number of different ways)			**Total Average Risk**	**% Increase**
0	0	0	$5.637*10^{-3}$	0
1:1,000,000	10^{-6}	$0.001*10^{-3}$	$5.638*10^{-3}$	0.018
1:100,000	10^{-5}	$0.01*10^{-3}$	$5.647*10^{-3}$	0.18
1:10,000	10^{-4}	$0.1*10^{-3}$	$5.737*10^{-3}$	1.8
1:1,000	10^{-3}	$1*10^{-3}$	$6.637*10^{-3}$	18

2.6 Economic Risk Evaluation

The level of tolerable economic risk from landslides is a function of an individual's or organization's financial ability to tolerate or survive the potential economic loss. Influencing factors can include income or revenue, net worth or market capitalization, access to insurance, societal responsibilities, awareness of the risks, and availability of suitable emergency response plans to help recover from the potential loss.

For example, large mining corporations and highway, railway and pipeline operators can often plan for, and recover from, multiple landslide incidents affecting their operations. Most local governments have much less experience and capacity to sustain economic losses caused by landslides. Most individual home owners, who typically do not have access to landslide insurance (see VanDine, 2011) have few options to financially recover from a landslide. Because of these different viewpoints, it is difficult to establish economic risk tolerance criteria for landslides that apply across a range of industries and organizational types and sizes, and individuals.

2.7 Qualitative Risk Evaluation

The potential consequences of landslides are wide ranging, and organizations and individuals have different levels of risk tolerance. Within some organizations there can also be a reluctance to express landslide risk in quantitative terms. In such cases, qualitative methods are useful to communicate and evaluate risks from landslides (and other hazards) and risks to a wide range of potential consequences. Risk management protocols can be assigned to a range of qualitative risk ratings.

Order-of-magnitude estimates of landslide likelihood of occurrence and consequence are typically required to assign a qualitative risk rating. Thus, qualitative risk evaluation usually requires some numerical calculations to assist with systematically assigning qualitative risk ratings. For consistency, it is suggested that the qualitative descriptor *moderate* represent the limit of tolerable risk for an organization or society. *Moderate* and *low* risks typically fall in the ALARP risk zone and are tracked for further review and risk reduction where practicable, whereas risks ranked as *high* or *very high* are considered intolerable and require risk control.

As one example, Table 2 shows the AGS' recommended qualitative terms for individual risk of loss of life from landslides (AGS, 2007). Using these qualitative descriptors, *moderate* risk represents the limit of tolerance for existing development that was adopted as the landslide risk tolerance criteria for the District of North Vancouver, BC (DNV, 2009).

Table 2. Sample Qualitative Descriptors for Risk of Loss of Life (after AGS, 2007).

Annual Probability of Loss of Life for the Individual Most at Risk	Qualitative Descriptor
>1:1,000	Very High
1:1,000 to 1:10,000	High
1:10,000 to 1:100,000	Moderate
1:100,000 to 1:1,000,000	Low
<1:1,000,000	Very Low

Figure 3 provides a sample qualitative risk evaluation matrix modified from many sources by BGC Engineering Inc. for application to landslide and other natural hazard risk assessments associated with large infrastructure projects. Likelihood and partial risk categories (the annual probability of a landslide occurring and reaching an element at risk) are shown on the vertical axis of the matrix; consequence categories for a range of potential consequences (safety, environment, social/cultural, and economic losses) are shown on the horizontal axis. Typically the likelihood and partial risk categories, and risk evaluation and response protocol, are kept constant, whereas the consequence descriptors are modified to match the landslide safety criteria established for a specific organization. For example, the economic loss category *Catastrophic* (risk evaluation and response column 6) would be adjusted to reflect the estimated economic loss that might lead to bankruptcy of the organization.

Multi-hazard Risk Evaluation Matrix (SAMPLE)

For the Qualitative Assessment of Natural Hazards

Partial Risk (annual probability)	Risk Evaluation and Response		
	VH	Very High	Risk is imminent; short-term risk reduction required; long-term risk reduction plan must be developed and implemented
	H	High	Risk is unacceptable; long-term risk reduction plan must be developed and implemented in a reasonable time frame. Planning should begin immediately
	M	Moderate	Risk may be tolerable; more detailed review required; reduce risk to As Low As Reasonably Practicable (ALARP)
	L	Low	Risk is tolerable; continue to monitor and reduce risk to As Low As Reasonably Practicable (ALARP)
	VL	Very Low	Risk is broadly acceptable; no further review or risk reduction required

Likelihood Descriptions	Indices		Probability Range						
Event typically occurs at least once per year	F	Almost certain	>0.9	M	H	H	VH	VH	VH
Event typically occurs every few years	E	Very Likely	0.1 to 0.9	L	M	H	H	VH	VH
Event expected to occur every 10 to 100 years	D	Likely	0.01 to 0.1	L	L	M	H	H	VH
Event expected to occur every 100 to 1,000 years	C	Possible	0.001 to 0.01	VL	L	L	M	H	H
Event expected to occur every 1,000 to 10,000 years	B	Unlikely	0.0001 to 0.001	VL	VL	L	L	M	H
Event is possible but expected to occur less than once every 10,000 years	A	Very Unlikely	<0.0001	VL	VL	VL	L	L	M

Description of expected negative outcome (Consequence)	Indices	1 Incidental	2 Minor	3 Moderate	4 Major	5 Severe	6 Catastrophic
	Health and Safety	No impact	Slight impact; recoverable within days	Minor injury or personal hardship; recoverable within days or weeks	Serious injury or personal hardship; recoverable within weeks or months	Fatality or serious personal long-term hardship	Multiple fatalities
	Environment	Insignificant	Localized short-term impact; recovery within days or weeks	Localized long-term impact; recoverable within weeks or months	Widespread long-term impact; recoverable within months or years	Widespread impact; not recoverable within the lifetime of the project	Irreparable loss of a species
	Social & Cultural	Negligible impact	Slight impact to social & cultural values; recoverable within days or weeks	Moderate impact to social & cultural values; recoverable within weeks or months	Significant impact to social & cultural values; recoverable within months or years	Partial loss of social & cultural values; not recoverable within the lifetime of the project	Complete loss of social & cultural values
	Economic	Negligible; no business interruption	<$10,000 business interruption loss or damage to public or private property	<$100,000 business interruption loss or damage to public or private property	<$1M business interruption loss or damage to public or private property	<$10M business interruption loss or damage to public or private property	>$10M business interruption loss or damage to public or private property

Figure 3. Sample Qualitative Risk Evaluation Matrix.

2.8 Selecting a Method of Evaluating Landslide Safety

A few organizations and approving authorities have formally adopted methods of evaluating landslide hazard and risk; most others have not. In the latter case, a landslide professional should determine which method of evaluating landslide safety is appropriate. This section suggests a process for making this determination for a number of examples.

2.8.1 Limit Equilibrium Slope Stability Analysis and Factor of Safety

Limit equilibrium slope stability analyses can be used to obtain reliable estimates of the factor of safety where the kinematic failure mode of instability are understood and where the basic model input parameters, such as stratigraphy, shear strength, groundwater conditions and external loads, can be determined with reasonable accuracy. Slope stability analysis can be used:

- to support the selection of residential setback guidelines from the top of potentially unstable slopes; taking into account the potential for future erosion at the base of the slope where appropriate;

- in conjunction with liquefaction susceptibility and lateral spreading or deformation analyses, to assess the level of landslide safety under earthquake loading scenarios; and
- to help assess and manage the level of landslide safety where it is determined that development is situated on a pre-existing deep-seated landslide.

The observational method, by which predicted ground conditions and slope behavior are made in advance and verified during construction and management of a slope, helps minimize the effects of parameter, model, and human uncertainty (Morgenstern, 1995). When used in conjunction with the observational method, with few exceptions slope stability analyses have been applied successfully to the design and management of "engineered" slopes such as cuts, embankment fills, and retaining walls, and for the design of structures located on or at the crest of potentially unstable slopes.

2.8.2 Partial Risk (Encounter Probability)

Where existing or proposed development is located downslope (not on the slope itself) of a potential landslide, or behind a potential retrogressive landslide, partial risk (also known as encounter probability) can offer a suitable means of evaluating landslide safety.

The application of partial risk criteria is best suited where it can be demonstrated that landslides pose a very low risk to an existing or proposed development, or where the probability of a landslide occurring and reaching the development is less than 1:10,000 per annum. Examples include:

- sites where Holocene-age landslide deposits are absent and no potential source of large-scale instability is identified up slope;
- sites located beyond the influence of the maximum credible landslide, such as outside of the rock fall shadow below a well-defined source area;
- sites located behind the potential extent of long-term landslide retrogression as determined through geological mapping, landslide inventory, and the use of ultimate slope angles (e.g., De Lugt et al. 1993); and
- sites where displaced material from the maximum credible landslide can be stopped by the design, construction and maintenance of physical barriers such as ditches, berms, catch nets or walls.

2.8.3 Quantitative Evaluation of the Risk of Loss of Life

For other situations it may be more appropriate to conduct a quantitative evaluation of the risk of loss of life and encourage the approving authority, in collaboration with the landslide professional, to compare the results against published landslide safety criteria. These special situations can for instance involve:

- sites located at the base of slopes or in the potential landslide runout zone;
- sites where it is impractical to demonstrate that the factor of safety for all landslides exceeds common acceptance criteria; and
- sites where providing for physical protection against all credible landslide effects is impractical.

2.8.4 Relative Ranking of Likelihood and Consequences

Relative ranking of the likelihood and consequences is typically used by operators of linear infrastructure, such as highways, railways and pipelines who often have to manage their operations across numerous landslides. In this approach an inventory of landslides is compiled and ranked, often using semi-quantitative methods that consider likelihood and consequences. The relative ranking is used to prioritize sites for follow-up inspection and mitigation. Examples include CN Rail's Rock Fall Hazard Risk Assessment program (Abbott et al., 1998); the BC Ministry of Transportation and Infrastructure's rock fall hazard rating system; and geohazard inspection programs managed by several operators of oil and gas pipelines in western Canada. In such circumstances, the number of sites addressed in a given year is often a function of the available capital or operating budget assigned to landslide management which, indirectly, is a reflection of the organization's landslide risk tolerance.

3. PUBLISHED LANDSLIDE SAFETY CRITERIA IN CANADA

Landslide safety criteria for residential development and public infrastructure should reflect societal values. Criteria should be established and adopted by local provincial and/or federal governments. Where such criteria are not available, landslide professionals can advise decision makers as to appropriate criteria based on the risk scenario and criteria adopted elsewhere.

The following summarizes landslide safety criteria that have been adopted or are in use in various jurisdictions across Canada. Much of the information is taken from Appendix C of APEGBC (2010). In that document landslide safety criteria are referred to as levels of landslide safety.

3.1 Canada

There are no nationally adopted landslide safety criteria in Canada.

The National Building Code of Canada 2005 (NBCC, 2005) only provides the statement, *Where a foundation is to rest on, in or near sloping ground, this particular condition shall be provided for in the design.*

The Canadian Foundation Engineering Manual (CGS, 2006), although it emphasizes foundation engineering, not landslides, contains several references to landslides:

- the possibility of landslides should always be considered, and it is best to avoid building in a landslide area or potential landslide area; and
- when a potential landslide area is identified, the area should be investigated thoroughly and designs and construction procedures should be adopted to improve the stability.

CGS (2006) does not provide landslide safety criteria. It does, however, address limit equilibrium analysis and factors of safety. Although limit states design is now mandatory for foundation design (NBCC, 2005), limit equilibrium analysis and factors of safety remain applicable for landslide analysis. From CGS (2006):

- factors of safety represent past experience under similar conditions;
- the greater the potential consequences and/or the higher the uncertainty, the higher the design factor of safety should be; and
- over time, similar factors of safety have become common to geotechnical design throughout the world.

CGS (2006) does not provide a range of factors of safety that address landslides specifically; however, based on data from Terzaghi and Peck (1948 and 1967), that document indicates factors of safety for earthworks (engineered fills) that range from 1.3 to 1.5, and for unsupported excavations (engineered cuts) that range from 1.5 to 2.0. CGS (2006) indicates a lower factor of safety can be acceptable if:

- a particularly detailed site investigation has been carried out;
- the analysis is supported by well documented local experience;
- geotechnical instrumentation to measure pore pressure and movement is provided and monitored at regular intervals to check the slope behaviour; or
- where slope failure would only have minor consequences.

CGS (2006) also addresses earthquake loading, and indicates:

- the NBCC (2005) has selected ground motions with a probability of exceedance of 2% in 50 years (1:2,475 per annum) for earthquake-resistant design purposes;
- the factor of safety of a slope under static conditions must usually be significantly greater than 1.0 to accommodate earthquake loads; and
- acceptable factors of safety depend on the uncertainty in the analysis, the soil parameters and the magnitude and duration of seismic excitation, in addition to the potential consequences of slope failure.

3.2 British Columbia

3.2.1 BC Building Code

Until 2010, the BC Building Code (BCBC, 2006) did not mention landslide safety for buildings. It stated only *Where a foundation is to rest on, in or near sloping ground, this particular condition shall be provided for in the design*. In December 2009, BC Ministerial Order M297 (BC, Province of, 2009) added:

> *The potential for slope instability, and its consequences, such as slope displacement, shall be evaluated based on site-specific material properties and ground motion parameters in Subsection 1.1.3 [of BCBC, 2006] and shall be taken into account in the design of the structures and its foundations.*

3.2.2 Seismic Slope Stability

In seismically active areas, earthquakes can trigger liquefaction or destabilize slopes leading to landslides or slope deformation. Section 4 and Appendix E of APEGBC (2010) provides recommendations for both methods of assessment and acceptance criteria. Guidance is based on consideration of earthquake ground motions with a 1:2,475 chance of exceedance, as per the NBCC (2005) and BCBC (2006). Where liquefiable soils may be present, it is recommended that a liquefaction susceptibility analysis be carried out. For other 'engineered' slopes, the following guidelines are provided:

- the use of k = PGA with a factor of safety >1.0 in a pseudo-static slope stability analysis is considered as too conservative, and is recommended as only a preliminary screening tool;
- methods by Bray and Travasarou (2007) are recommended to estimate median slope displacements for the design earthquake;
- the proposed procedure is intended to define the critical slip surface that has an estimated 15 cm of median displacement so that the building can be located behind the critical slip surface;

- the tolerable slope displacement of 15 cm is proposed as a guideline, based on experience with residential wood-frame construction. This guideline is not intended to preclude the landslide professional from selecting another value that he/she deems appropriate; and
- since the estimated displacements are median estimates with a 50% of exceedance during the design earthquake (with a 1:2,475 return period), the proposed tolerable slope displacements roughly correlate with a partial risk (of structures being subjected to >15 cm of slope displacement) equal to a 1:5,000 chance of exceedance.

Further details can be found in APEGBC (2010).

3.2.3 Ministry of Transportation and Infrastructure

In British Columbia, the Ministry of Transportation and Infrastructure (BC MOTI) is the approving authority for rural subdivision approval outside of municipal boundaries and within those Regional Districts that have not assumed the role of the rural subdivision Approving Authority.

In 2009, BC MOTI Approving Officers provided guidance on landslide safety criteria in a document entitled "Subdivision Preliminary Layout Review - Natural Hazard Risk." With respect to landslides, landslide safety criteria, paraphrased from that document, are as follows:

- for a building site, unless otherwise specified, an annual probability of occurrence for a damaging landslide of 1:475 (10% probability in 50 years);
- for a building site or a large scale development, an annual probability of occurrence of a life-threatening or catastrophic landslide of 1:10,000 (or 0.5% in 50 years); and
- large scale developments must also consider total risk and refer to international standards.

This guidance document has not yet been published and until the terms 'damaging' and 'life-threatening' are clearly defined, BC MOTI Approving Officers should be contacted for further details.

Although the probabilities above are indicated as probabilities of occurrence in APEGBC (2010), this is considered to be incorrect terminology; they should be considered as probabilities of partial risk (VanDine, pers comm).

3.2.4 Fraser Valley Regional District

In the 1990's the Fraser Valley Regional District published landslide safety criteria for that Regional District for various types of natural hazards for a range of residential development (Cave 1992, revised 1993). These criteria, which are current today, were based on:

- an interpretation of Mr. Justice Thomas Berger's 1973 decision that a return period of 1:10,000 years for a potentially catastrophic landslide affecting a proposed subdivision was unacceptable (Berger, 1973);
- The 200-year return period for provincially sponsored flood-proofing; and
- The BC MOTI's guideline of 10% probability in 50 years (BC MOTI, 1993).

The criteria are lower (return periods as high as 1:50 per annum) for proposed modifications to existing development, while higher standards apply to new development. Higher landslide return periods (as high as 1:1,000 per annum) are tolerated for small landslides with potential to impact a single new residential structure, while only very low landslide return periods (<1:10,000 per annum) are tolerated for larger landslides with potential to impact a new subdivision. Implicitly, therefore, the criteria are risk-based. Although the probabilities above are indicated as probabilities of occurrence in APEGBC (2010), this is considered to be incorrect terminology; they should be considered as probabilities of partial risk (VanDine, pers comm).

3.2.5 District of North Vancouver

Two scenarios commonly encountered in the District of North Vancouver (DNV) are:

- existing or proposed residential developments at the base of steep slopes or on debris-flow fans; most amenable to a risk of loss of life method (Section 2.8.3 above); and.
- existing or proposed residential developments and associated retaining structures on or at the crest of slopes; most amenable to a limit equilibrium slope stability analysis and factor of safety method (Section 2.8.1 above).

Landslide safety criteria were proposed by DNV staff based on discussion and review with landslide professionals and a task force of community citizens convened specifically to explore this issue. The criteria were adopted by DNV Council in 2009 (DNV, 2009).

The DNV criteria were established to help evaluate landslide risk to life associated with both existing and proposed residential developments and for the two common development scenarios described above. They were also established to be compatible with recommended approaches to the landslide risk assessments outlined in APEGBC (2008, a prior version of APEGBC 2010) including use of the landslide assurance statement and the guidelines for seismic slope stability assessment contained in that document. The criteria are summarized in Table 3.

These landslide safety criteria are applied at the development and building permit phases of development. Additional details are presented in Porter et al. (2007) and Porter et al. (2009).

Table 3. DNV Landslide Safety Criteria (DNV, 2009).

Application Type	**Risk <1:10,000**	**Risk < 1:100,000**	**FS >1.3 (static); 1:475 (seismic)**	**FS >1.5 (static); 1:2,475 (seismic)**
Less than 25% increase in building footprint	X		X	
Repair or replace retaining structure				X
New residence, new retaining structure, or >25% increase in building footprint		X		X

Notes:

1. Risk = annual probability of fatality for individual most at risk
2. FS = limit equilibrium factor of safety for global failure
3. Seismic slope stability criteria based on specified ground motion chance of exceedance and either FS >1.0 or ground deformation <0.15 m in non-liquefiable soils, as per APEGBC (2010)
4. In addition to meeting these criteria, landslide risks must be reduced to ALARP so that the cost of further risk reduction would be grossly disproportionate to any risk reduction benefits gained.

3.3 Alberta

3.3.1 City of Calgary

Factor of safety based landslide safety criteria are utilized to guide residential development in the City of Calgary. Guidance documents on slope stability (Calgary, City of 2008 and 2009) state that:

- a geotechnical report, prepared by a qualified geotechnical engineer, is required for all sites where existing or final design slopes exceed 15% or where, in the opinion of the City Engineer, acting reasonably, slope stability is a concern;
- no development shall occur if the factor of safety against slope failure is less than 1.5;
- lands with a factor of safety equal to or greater than 1.5 will be acceptable for development from a slope stability point of view;
- if the factor of safety is less than 1.5, subject to the approval of the appropriate approving authority, the slope may be modified using remedial measures which are to the satisfaction of the City Engineer, to increase the factor of safety to a minimum of 1.5, thus increasing the area of developability; and
- the setback limit, based on a minimum factor of safety of 1.5 shall be shown on the final development plan.

3.4 Ontario

The Ontario Ministry of Natural Resources published a guide that describes the province's Natural Hazards Policies (3.1) of the Provincial Policy Statement of the Planning Act (OMNR, 2001). It provides some guidance on landslide safety criteria which are used by municipal and regional approving authorities. Two examples are provided below.

3.4.1 Great Lakes and St Lawrence River Slope Setback Guidelines

Setback guidelines from potentially unstable slopes have been established for some approving authorities along the Great Lakes and St Lawrence River, and other river and stream systems (for example, Cataraqui Region Conservation Authority, 2005). Most of these guidelines call for setbacks that include an allowance for a prediction of 100 years of toe erosion (an erosion allowance) and a stable slope allowance that reflects the long term stability of the existing soil material. Along rivers and streams, an 'erosion access' allowance is also often required to provide access to the site for emergencies, regular maintenance, or unforeseen conditions. If development is proposed within these established limits, a site-specific geotechnical investigation is required.

3.4.2 City of Ottawa

The City of Ottawa has prepared *Slope Stability Guidelines for Development Applications* (Golder Associates Ltd, 2004). In these guidelines, unstable slopes (referred to as *hazard lands)* are defined as those that have a factor of safety of less than 1.5 against slope failure (less than 1.1 for seismic loading conditions). Where appropriate, allowances must also be provided for potential extreme retrogression of flow slides in sensitive clays, future toe erosion, and in some cases, an additional allowance for access to future slope failures. Development of permanent structures, including residential development, is typically precluded within *hazard lands*.

3.5 Other Jurisdictions

The Province of Saskatchewan has developed a relative ranking of landslide hazards and risks to aid in prioritizing and mitigating landslides affecting provincial highways (Kelly et al., 2004).

The City of Winnipeg, MB, is developing a relative ranking of landslide hazards and risks affecting public lands within the city (James, 2009).

Most other Canadian provinces, territories and municipal approving authorities have policies or guidelines that outline the need for landslide assessments and types of assessments that should be undertaken (for example in the Saguenay-Lac-Saint-Jean region of Quebec, Bilodeau et al. 2005). However, the authors are not aware of any other formally adopted provincial or municipal landslide safety criteria for residential development. Such criteria likely do exist or are in preparation, and as such criteria are brought to the attention of the GSC, it is hoped they will be incorporated into future versions of the *Canadian Technical Guidelines and Best Practices related to Landslides*.

3.6 Requirements for Provincial and National Landslide Safety Criteria

Most of the published landslide safety criteria described above have been developed by local governments (municipal or regional districts) in the absence of provincial or national standards and in response to the types of landslides and development pressures faced in those jurisdictions.

What works well in one municipality or regional district is not necessarily appropriate in another.

However, there are considerable benefits to establishing provincial and/or national landslide safety criteria. Such benefits include:

- more consistent landslide safety criteria between local governments and provinces;
- improved communication between developers, landslide professionals, approving authorities, insurance providers, real estate agencies, and the public; and,
- in some cases reduced levels of landslide risk in jurisdictions where criteria have not been established.

To be applicable across geographically diverse regions and a wide range of development scenarios, such guidelines likely require reference to a range of landslide risk evaluation and risk assessment methods and recommendations to landslide professionals on which methods are appropriate for given conditions and circumstances. Based on the review of available published guidelines, one or more of the following criteria are suggested as appropriate for proposed new residential development:

- <1:10,000 per annum probability for a landslide occurring and reaching the area of proposed development;
- <1:100,000 per annum risk of loss of life to individuals most at risk;
- group or societal risk of loss of life evaluated on an F-N curve, with the ALARP or broadly acceptable regions as the landslide safety criteria;
- tolerable slope deformation under seismic loading = 0.15 m (where it can be demonstrated that
  soils are not prone to earthquake-triggered liquefaction); and,
- where appropriate, an allowance for 100 years of predicted toe erosion along river, lake, ocean, or reservoir shorelines.

It is suggested that less stringent criteria, that is, risks up to one order of magnitude higher, may be appropriate for ongoing occupation of, or the approval of minor modifications to, existing residential development. Greater risks may also be tolerable for employees of organizations with infrastructure exposed to known landslides, provided systematic procedures are followed to understand, prioritize and manage the risks.

Landslide safety criteria based on factors of safety would also be beneficial and are under review. These will need to take into consideration variables such as soil or rock type, site investigation effort, and the methods of analysis used to estimate the factor of safety. Under special circumstances, less stringent factor of safety criteria may also be appropriate for development on large, stabilized landslides if it can be demonstrated that landslide failure geometry and groundwater conditions are clearly defined through very detailed geotechnical investigation and analysis, and that strengths acting on the landslide shear surfaces are already at residual values.

4. COMMUNICATION AND CONSULTATION

As shown on Figure 1, and as introduced in VanDine (2012), risk communication and consultation are key components of the landslide risk management process and should be carried out during all stages of the risk management process.

During the early stages of addressing a landslide hazard or risk, communication typically focuses on describing the potential risk scenario(s) and the process to be followed to characterize hazards and assess risks. Consultation focuses on establishing stakeholder objectives, the types of elements at risk, and the values that the stakeholders place on those elements. Maps, photographs and schematic illustrations are very useful to help convey technical information.

Once risk estimates are available, communication focuses on an improved description of the potential landslides causative factors, the associated hazards, the potential range of consequences, and the estimated risk levels. Uncertainties need to be described along with proposed methods of managing uncertainty. Risk levels need to be placed into context through analogy (for example, comparison with other risks that stakeholders encounter in everyday life). If landslide safety criteria have not been established, consultation is needed to address what levels of risk the stakeholders are willing to tolerate and how those compare with what is used in other jurisdictions.

Where, through comparison with available landslide safety criteria or through the consultation process, it is determined that landslide risks are unacceptable, the communication process needs to focus on describing the range of options available to reduce risk, the associated costs, the likelihood of success, and ongoing maintenance requirements to treat residual risks. The feasibility and cost of achieving extremely low risk levels needs to be described. Consultation is required to determine stakeholder preferences for risk treatment.

During the treatment and monitoring phases, communication can involve use of warning signs, publication of hazard and risk maps and technical reports, testing of emergency response protocols, and making the results of instrument monitoring, slope inspection and updated hazard or risk ratings available to interested stakeholders. Web-based communication of landslide stabilization, monitoring and inspection results is becoming a more feasible and common means of timely dissemination of information to interested stakeholders.

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