Interim Risk Criteria for Landslides and Boulder Falls from Natural Terrain

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Abstract: Natural hillsides cover over 60% of the total land area of Hong Kong. Current Government's policy is to avoid hazards from natural hillside wherever possible when planning new developments and to react to known hazards. Given the scarcity of land in Hong Kong, this is becoming increasingly difficult.

Significant natural terrain landslides in recent years drew attention to the hazards of destructive landslides from the natural hillside. The threat is likely to increase if more land on or adjacent to steep hillsides is to be released for housing to meet the projected population demand. Studies were initiated by the Geotechnical Engineering Office to develop state-of-the-art methodologies for quantification of landslide risk and establish appropriate risk criteria.

This paper summarises the pilot work carried out in developing risk guidelines for landslides and boulder falls from natural terrain. The interim risk criteria are explained and their implementation is discussed.

INTRODUCTION

Natural hillsides cover over 60% of the total land area of Hong Kong. In the past 50 years, four people are known to have been killed by boulder falls from natural hillsides in two separate incidents, but there is no known fatality caused by landsliding on natural hillsides which has not been triggered by human activities. Recognising that landsliding and boulder falls are an on-going natural process in the geological evolution of our hillsides, current Government's policy is to avoid hazards from natural hillside wherever possible when planning new developments and to react to known hazards. Given the scarcity of land in Hong Kong, this is becoming increasingly difficult.

Significant natural terrain landslides (e.g. Tsing Shan in 1990 and Tung Chung in 1992 and 1993) in recent years drew attention to the hazards of destructive landslides from the natural hillside. The threat is likely to increase if more land on or adjacent to steep hillsides is to be released for housing to meet the projected population demand. Accordingly, a new natural terrain landslide risk management strategy is being developed by the GEO. As part of this, studies were initiated to develop methodologies for quantification of landslide risk and establish appropriate risk criteria.

This paper summarises the pilot work carried out in developing risk guidelines for landslides and boulder falls from natural terrain. The study involved a review of the approaches taken in the development of risk tolerability criteria world-wide for major hazard installations, railway operations, dams and landslides. The interim risk criteria are explained in this paper, together with a discussion of their practical implementation.

INDIVIDUAL AND SOCIETAL RISKS

The basics of quantitative risk assessments (QRA) are explained by Wong et al (1997). The findings of a risk assessment are presented in terms of the individual risk, which relates to the risk posed to a single person at a specific location, and societal risk, which expresses the risk to the affected population as a whole.

There are two definitions of individual risk commonly used in QRA. Individual risk (IR) is the frequency of harm, per year, to a notional individual exposed to a hazard for 100% of the time, whereas personal individual risk (PIR) is the frequency of harm per year to an actual vulnerable individual with account taken of the temporal exposure and the likelihood of escape or protection from the hazard.

Societal risk is usually expressed as an F-N curve, which is a graphical representation of the cumulative frequency of N or more fatalities (denoted as F), plotted against the number of fatalities (i.e. N), on a log-log scale. This representation of societal risk reflects the potential for accidents involving a large number of fatalities.

Risk evaluation generally involves the assessment of whether the assessed risk level is so great or the

outcome is so unacceptable that it must be reduced at all cost, or whether the risk is so small that no mitigation measure is necessary. If the risk falls between the two limits, then conventional risk management concept involves taking action to reduce it to the lowest level practicable, with due regard to the benefit derived and the costs of further mitigation. In other words, risks must be reduced to a level which is 'As Low As Reasonably Practicable', commonly referred to as the ALARP principle. This is broadly equivalent to that adopted in the Health and Safety at Work Act (1974), and is the basis of the approach adopted by the UK Health and Safety Executive (HSE) in its regulation of the major hazard industries.

RISK CRITERIA IN CURRENT USE IN OTHER INDUSTRIES

A number of countries, such as Hong Kong, the Netherlands, UK and Australia, have adopted the use of QRA techniques for major potentially hazardous technological installations, including the establishment of risk criteria. The salient aspects are briefly reviewed in the following.

Hong Kong

Hong Kong have introduced risk guidelines for individual and societal risks for Potentially Hazardous Installations (PHIs) which are applied in land-use planning since about the late 1980s (Wrigley & Tromp, 1995). These were formulated essentially by means of benchmarking against international practices, with suitable refinement to suit local conditions.

The individual risk criterion is that the maximum (Personal) Individual Risk of offsite fatality must not exceed 10^{-5} per year. The criterion does not take account of different population types.

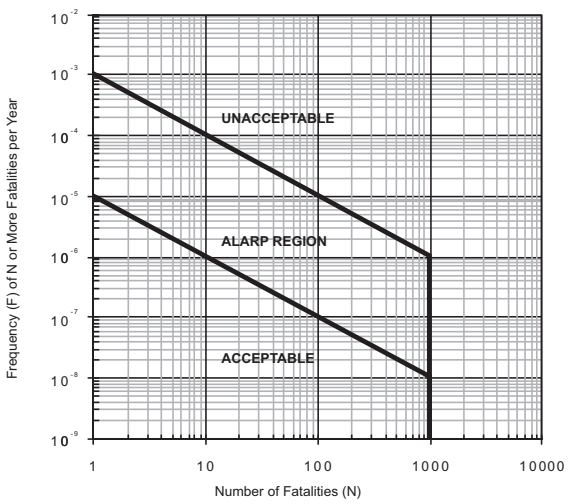

Figure 1. Hong Kong Government PHI societal risk criteria

The societal risk criteria for PHI are shown in Figure 1. There are three regions, namely:

- Unacceptable region;
- ALARP region;
- Acceptable region.

The guidelines have been applied to all old and new PHIs. They are intended for use as guidance in the decision-making process in land use planning, although in practice the criteria have often been adhered to fairly rigidly.

In the risk guidelines, a maximum fatality level is taken to be 1,000, i.e. it is unacceptable to kill 1,000 people or more in a single incident, unless the chance of this occurring is less than 10^{-9} per year (which is considered effectively as a non-credible event). The 1,000 fatality level in Hong Kong for PHIs was intended to account for society's aversion to high fatality events. In practice, the 1,000-fatality cut off has proved to be a very stringent criterion, where dense population in high-rise flats, is often found close to LPG installations.

The above approach to risk guidelines in Hong Kong is currently being reviewed by some Government Departments, with consideration being given to refinement of the approach to take account of vulnerable members of the population (e.g. old, young or infirm).

The Netherlands

In the Netherlands, the ALARA principle is applied to both the individual and societal risks, i.e. risk should be reduced to a level 'As Low As Reasonably Achievable' using the best available technology.

The maximum permissible individual risk level to exposed population is 10^{-6} per year for new situations and 10^{-5} for existing situations. Furthermore, land use policy requires that no new developments be permitted inside the 10^{-6} contour around an existing installation except in special circumstances. No account of occupancy, escape or protection factors is taken in the individual risk calculations. The societal risk criterion gradient is at a value of minus 2 which means strong risk aversion to multiple fatality events.

There has been on-going debate and review of the Netherlands' risk criteria with the latest revisions to the societal risk criteria involving the elimination of the previous 'acceptable' line on the F-N plot, such that there will now only be two zones, i.e. an 'unacceptable' region and an ALARP region. This change in policy is considered necessary due to the realisation of the difficulties in applying tolerability criteria on F-N curves as a decision tool for land use planning. It should be noted that the societal risk criterion is used for guidance only and is not intended to be strictly applied.

UK

The values proposed by the HSE for individual risk for the upper and lower boundaries of the ALARP region are 10^{-4} and 10^{-6} per year respectively for members of the public living close to a nuclear power station or other major hazard facilities.

At present the HSE does not use formal standard societal risk criteria for fixed installations in decision-making. However, it considers societal risk in a simplified way for housing developments near existing installations. Qualitative judgements are made for land use planning decisions using some surrogate judgements based on the individual risk criteria.

Australia

For hazardous installations, the Australian (New South Wales) Government has adopted individual risk criteria but have avoided the use of societal risk criteria. Different individual risk criteria have been developed to take account of different types of development, e.g. industrial, residential and commercial.

The individual risks are calculated taking no account of occupancy, escape or protection factors. The criteria are given in Table 1.

Table 1. Individual Risk Criteria in Australia

Land Use	Suggested Values (per year)
Hospitals, schools, child care facilities, old age housing	5×10^{-7}
Residential, hotels, motels, tourist resorts, etc.	10^{-6}
Commercial developments including retail centres, offices and entertainment centres	5×10^{-6}
Sporting complexes and active open space	10^{-5}
Industrial	5×10^{-5}

With regard to societal risk, the NSW Department of Planning are of the view that more research is needed before adopting specific criteria for societal risk. They consider that acceptability of societal risk is complex and that this is specific to each society of differing culture. However, a qualitative approach is taken in making judgement on each case by evaluating risk contours around the facility and taking into account vulnerability of the public and types of development.

RISK CRITERIA FOR DAMS

Much work has been done to explore the feasibility of using formal risk management techniques to assess dam safety, e.g. Canada, Australia, USA, the Netherlands and Norway. The various risk criteria proposed are reviewed by Fell & Hartford (1997). The salient aspects of some of these criteria are presented below.

BC Hydro, Canada

Individual Risk: BC Hydro's individual risk criteria include an upper limit of 10^{-4} per annum in respect of the total risk to an identified individual from dam failure. The total risk is taken to be the sum of the risks due to the various sources (e.g. flooding, earthquake, reservoir slope instability and internal erosion). The ALARP principle is adopted.

Societal Risk: Only an upper limit line for 'intolerable' risk is defined, with risks above this line being considered 'intolerable', whilst risk levels falling below the line taken as 'tolerable', providing that the ALARP principle is demonstrated. There is no lower limit line for 'tolerability'. It is of interest to note that the plot does not actually refer to the cumulative frequency of N or more fatalities, but rather the "Annual Probability (or "frequency") of Dam Incidents". Also, the criteria address "Economic Losses", with a US$10 million loss considered to be equivalent (in terms of tolerability) to 1 fatality.

Australian National Committee on Large Dams (ANCOLD)

ANCOLD (1994) proposed the following risk criteria for new and existing dams:

Individual Risk: For new dams and upgrading of existing dams, the maximum individual risk to a member of the public is 10^{-5} per annum, whereas the average risk of death to particular members of the public from dam failure (i.e. personal individual risk) should not exceed 10^{-6} per exposed person per annum.

Societal Risk: The criteria are being revised and will be less conservative than the previous criteria established by ANCOLD, which adopted a higher aversion factor for high fatalities, with the slope being greater than -1 at the high fatality end, i.e. the F-N tolerability lines on a log-log scale are curved. The revised F-N risk criteria now have a constant gradient of -1, with the 'unacceptable' limit on frequency being truncated at 10^{-6} per annum, which stems from ANCOLD's view that it is unrealistic to design a dam with a sufficient degree of accuracy for a failure probability lower than 10^{-6} per annum. This is an unusual feature for F-N curves and implies that it is no more unacceptable to kill 10,000 persons than 100 persons if the failure probability is less than 10^{-6} per annum.

US Bureau of Reclamation (USBR)

Whilst the upper limit line of their proposed acceptable societal risk criteria coincides with the BC Hydro and the modified ANCOLD criteria, the USBR criteria are applied for each loading case (i.e. static, seismic, flood, etc), whereas the BC Hydro and ANCOLD criteria apply to the total risk. The USBR criteria are therefore comparatively less conservative.

RISK CRITERIA FOR LANDSLIDES IN OTHER COUNTRIES

A review of international practice indicates that there are as yet no risk criteria established by a government authority specifically for landslides. However, some work has been done by Morgan (1991), Cave (1992), Hungr et al (1993), Fell (1994), Sobkowicz (1996) and Fell & Hartford (1997).

Fell (1994) examined various approaches used to assess the tolerable risk levels and concluded that the public may tolerate relatively high risks from natural landslide hazards compared to that from an engineered slope.

DEVELOPMENT OF RISK CRITERIA FOR NATURAL TERRAIN LANDSLIDES IN HONG KONG

Ideally, the appropriate risk criteria should take account for the community's perception of the nature of the risk, the society's ability and willingness to pay for risk control and international practice and norms in the standard of risk-taking. Given the experience with the use of formal risk management concepts in the PHI field in Hong Kong, a reasonable starting point in the establishment of risk criteria for natural terrain landslide hazards would be to benchmark the yardstick with reference to the PHI criteria, with suitable adjustments to account for the differing nature of risks involved, as appropriate. The objective was to derive risk criteria for interim trial use, and their practicality will be tested in site-specific landslide QRA studies.

Scaling for Voluntary Risk

Consideration has been given to assessing whether it would be appropriate to scale the PHI risk criteria to account for an element of voluntariness in the case of landslide risk. Whilst it may be valid to adopt a higher, or less conservative, criterion for squatters on natural terrain, for new or existing permanent developments affected by natural terrain landslides, the public is unlikely to consider such risks as voluntary. Exposure to natural terrain risk may be subconscious, as awareness of such risk may either be inaccurate or absent. The public probably expects that the Government would take steps to ensure that the landslide risk levels are low enough before permitting developments to proceed.

Overall, the balance of the argument does not seem to favour any scaling factor to be applied to the PHI criteria to account for voluntary risk exposure to landslide risk.

Scaling for Natural Hazards

The literature review suggests that in some countries, the public may tend to tolerate higher levels of risk from natural terrain landslides than for a man-made slope (which may be taken to be equivalent to an PHI in the context of an engineered structure), on the basis that this could be taken as a natural disaster and fairly rare events. Such incidents are sometimes regarded as 'acts of God' and correspondingly the risk tolerance level may be justifiably taken to be higher than cases where man can directly control the risk. In the case of natural terrain in Hong Kong, several hundreds landslides occur every year and they are hardly rare events. From a conceptual and social science viewpoint, it is considered that the public in Hong Kong would probably perceive a strong element of human involvement and that the community is likely to be no more tolerant of its risk compared that posed by a PHI. In practice, it is questionable whether the public is able to distinguish between a man-made slope and natural hillside. There is also the added complication that some of the natural terrain landslides are triggered by human actions. Whether the community can afford to target at a lower risk tolerance level in the case of natural terrain landslides is a key issue and this would need to be examined in detail separately.

In view of the above, the interim risk criteria developed for natural terrain landslide hazards have not been relaxed to account for a natural event involving the forces of nature.

Distinction between Existing and New Developments

The risk literature generally supports the tendency for the public to be comparatively less tolerate of the calculated risk for a new development than for an existing development. This is partly related to the expectation that advancement in technology and knowledge over the years should bring with it reduced risk. An order of magnitude difference is considered appropriate to account for this.

Individual Risk Criteria

The following are recommended as the interim risk criteria:

Type of development	Maximum allowance individual risk
New	10^{-5}
Existing	10^{-4}

Taking cognizance of the latest thinking in risk assessments for PHI, it is suggested that the proposed individual risk criteria should be applied to the most vulnerable person affected by the hazard. This would err on the cautious side. Further work will be done to examine whether or not this may turn out to be overly conservative.

No ALARP region has been incorporated in the individual risk criteria, which is consistent with the current PHI criteria. The basis for this is that demonstration of ALARP is best done by means of cost-benefit analysis using the societal risk measure of Probable Loss of Life (PLL), as in standard risk assessment practice in Hong Kong which has worked well in the past.

Societal Risk Criteria

The main considerations in the development of societal risk criteria relate to whether a 3-tier (the conventional approach) or 2-tier system (consistent with the latest thinking in the Netherlands) should be adopted, and the appropriate gradient of the lines on the F-N plot.

Detailed deliberations have been given to assessing the feasibility of deriving suitable societal risk criteria by calibrating the overall residual risk level implied by the PHI criteria. In addition, due regard was give to the draft risk criteria being considered for transportation of dangerous goods in Hong Kong. However, this approach has not been successful given the complications and uncertainties involved. Reference should be made to ERM (1998) for a detailed discussion on this.

Two options have been recommended as the interim societal risk criteria. Option A (Figure 2) adopts a 2-tier approach, with an ALARP zone being applicable to scenarios where the assessed risks fall below the 'unacceptable' line. In practice, the effort generally spent on debate and discussion in relation to the acceptable or tolerable line may outweigh the effort associated with a simple cost-benefit analysis to demonstrate the ALARP principle. The 2-tier concept is also consistent with the public expectation that the best will be done in all respects to reduce risk. There may be concerns that this approach will lead to an apparently open-ended requirement for expenditure on risk reduction. However, it should be noted if the calculated risk is small, so will the calculated justifiable expenditure on risk mitigation. The practical implications of this option will be assessed in detail in trial applications to specific sites.

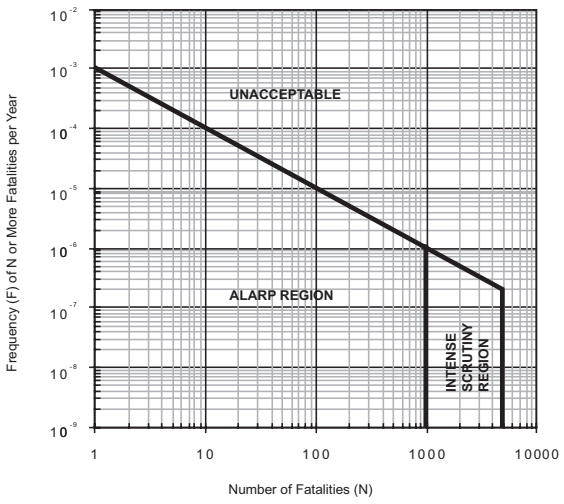

Figure 2. Proposed societal risk criteria for landslides and boulder falls from natural terrain (Option A)

The alternative Option B (Figure 3) is similar to Option A, except that it is based on a 3-tier approach, incorporating a 'broadly acceptable' zone.

In both options, the limit of tolerability in terms of the number of fatalities from a single event has been extended from the 1,000 fatalities used in the current PHI criteria, which is considered restrictive particularly in the case of natural terrain landslides, to 5,000 fatalities. The zone defined by the 1,000 and 5,000 fatalities is designated an 'Intense Scrutiny' region. This will provide an option for the regulators to permit certain types of developments taking due consideration of the societal needs and benefits.

IMPLEMENTATION OF THE SOCIETAL RISK CRITERIA

Careful thoughts are needed in the implementation of the societal risk criteria. In the case of an PHI, the risk criteria are applied principally to the PHI itself, i.e. assessing the tolerability of risk of a proposed or existing PHI to the community. In the case of landslides, however, the criteria need to be applied to the development site that may be affected, i.e. assessing the tolerability of risk in a specific site posed by the natural terrain and not to the natural terrain (which is equivalent to the PHI) itself. The situation will obviously become more complicated when the development site is affected by many natural terrain units or when the natural terrain unit is affecting many development sites.

In order to apply the risk criteria for practical use, it is necessary to define a unit area that is liable to be affected by the natural terrain landslides for consideration in the QRA. This is a complex issue as the size of the 'consultation zone' is an integral part of the risk criteria for natural terrain, unlike in the case of the PHI criteria where the 'consultation zone' is only a technical aspect of the risk assessment and not directly related to the risk criteria. Reference to the data on runout in the Natural Terrain Landslide Inventory (Evans et al, 1997) and cognizance is taken of the 'consultation zone' that would be imposed for an PHI affecting a comparable number of vulnerable

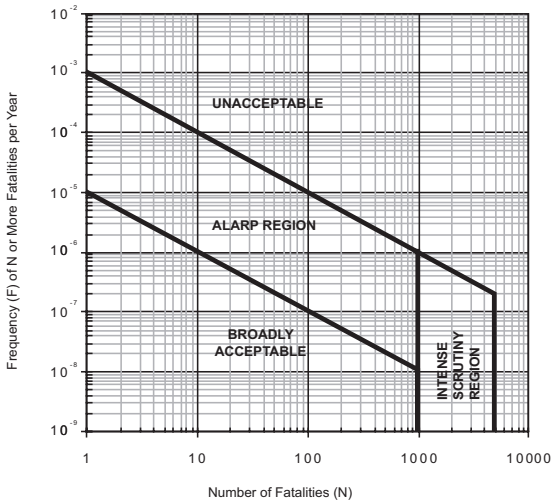

Figure 3. Proposed societal risk criteria for landslides and boulder falls from natural terrain (Option B)

population. Based on these, it is proposed, as a starting point, to adopt an approach whereby the influence zone of natural terrain landslides extends a distance of 150 m from the toe of the hillside. This will correspond to a reference toe length of natural terrain of 500 m based on correlation with the comparable 'consultation zone'. It should be noted that the distance of 150 m is used to derive the reference toe length which is an integral part of the societal risk criteria. For an QRA, a flexible approach is needed to take due account of the characteristics of the catchment and the nature of the landslide hazards in deciding on the appropriate influence zone to be considered.

If a development involves greater areas of natural terrain such that the reference length of 500 m is exceeded, then an appropriate linear scaling factor should be used. For instance, in the case of a very large development affected by natural terrain with an equivalent toe length of 5 km, then it follows that the limiting societal risk criteria should be increased by one order of magnitude. On the other hand, if the development involves less than 500 m equivalent toe length of natural terrain, then the same criteria as proposed are taken to apply, i.e. the acceptance criteria will not be scaled down as such.

It is recognised that the above simplified approach is relatively crude and the rationale for the correlation with the PHI's 'consultation zone' is not rigorous in that it may not necessarily be comparing like with like. It is intended that this semi-empirical and pragmatic approach will be critically reviewed following trial use.

Various approaches to be adopted in cost-benefit analysis including the value of a statistical life, which forms an integral part of the risk evaluation process to assist decision-making, have been discussed in ERM (1998). In addition, ERM (1998) also proposed an approach for incorporating adjustment factors in cost-benefit analyses to account for public aversion against multiple deaths in a single event.

CONCLUDING REMARKS

The proposed individual and societal risk criteria are intended to apply to the total risk posed by natural terrain hazards, including landslides and boulder falls. It should also be recognised that the quantified risks will have considerable uncertainties and that the criteria may in practice be an imprecise representation of what the community desires. Hence, the estimated risks should not be regarded as absolute and the risk criteria should not be taken as mandatory but rather only as guides to decision-making.

The proposed risk criteria are interim recommendations for trial use in site-specific QRA studies of natural terrain landslide hazards. Further work will be warranted to explore other means of defining or refining the interim risk criteria, such as assessing public perception and expectations by social science techniques, and examining the cost-benefit implications of the criteria. Suitable refinement will be made where necessary and the geotechnical profession will be widely consulted before the risk guidelines are finalised. In the meantime, the interim guidelines can be used as a basis for the evaluation of QRA results for developments, such as buildings and roads, affected by natural terrain landslide hazards.

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