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Study on the Acceptable and Tolerable Risk Criteria for Landslide Hazards in the Mainland of China

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ABSTRACT: In recent years, demands for performing landslide quantitative risk assessments are increasing. Quantitative risk acceptance criteria must be established before performing quantitative risk assessment (QRA). Applying the results of such assessments is highly dependent on the definition of risk levels. Acceptance criteria applied in risk analysis are recapitulated. The current practice of authoritative acceptance criteria formulation is discussed from a decision theoretical point of view. Besides, some existing risk acceptance criteria applying the ALARP principle based on the established safety goals and quantification of these (containing the individual risk, economical risk, societal risk and environmental risk) are provided. The interim risk criteria are explained and their implementation is discussed. Finally a number of problems, such as whether the phenomenon of risk aversion of concern to the authority or to the owner, are discussed.

1 INTRODUCTION

Study on accepted risk level of landslide hazard is a new topic in recent years, and the accepted standard has not been set up at present. Latter (1969) suggested that the number of deaths caused by landslides can be used as a measure of the magnitude of a landslide disaster. Morgan (1991, 1997), Fell and Hartford (1997) and Evans (1997) all attempted to establish landslide risk levels, and related definition criteria, on the basis of the number of people killed by slope movements. Ditlevsen (1996, 2003) discussed the current practice of authoritative acceptance criteria formulation from a decision theoretical point of view. The ISSMGE TC32 (International Society for Soil Mechanics and Geotechnical Engineering - Technical Committee on Risk Assessment and Management, 2004) defined acceptable risks as risks which everyone impacted is prepared to accept. However, the challenge is to determine what the threatened individuals and society are willing to accept, as each person perceives and subsequently accepts risks in a different way.

Although levels of acceptable risks are already developed in many countries for decades, such risk acceptance levels are rarely related to landslides. But research in this area is still blank in China, even fewer persons (M. Wang, 2001; Zuyu Chen, 2003) have a more thorough understanding of the problem.

Before presenting the results of risk analysis, it is important that the criteria be established against which the risks will be evaluated. Therefore, the following section discusses the risk criteria considered appropriate for this study. Firstly, some general principles of and approaches to defining acceptable and tolerable landslide risk levels are briefly reviewed, followed by a discussion of how acceptable and tolerable risks are treated in other fields and different countries. Secondly, some

acceptable levels of landslide risk are provided and the estimated risks to life and financial risks are then presented and evaluated in light of the suggested criteria.

2 ACCEPTABLE AND TOLERABLE RISKS

2.1 Definitions for risk criteria

From a risk management perspective, risk criteria are the means by which the results of a risk analysis can be translated into recommendation on whether the risk should be tolerated, or whether there is justification for taking (further) measures to reduce it. As such, they are intended as anchor points within a structured and repeatable decision making process for prioritizing safety investment. It is important therefore that the risk criteria provide a complete framework for decision making.

It is important to distinguish between acceptable risks which a society desires to achieve, particularly for new projects, and tolerable risks which they will live with, even though they would prefer lower risks (AGS, 2000). This applies to both property and loss of life. Acceptable and tolerable risks for property loss and damage must be determined by the client, owner and if appropriate, regulator.

Acceptable Risk – A risk for which, for the purposes of life or work, we are prepared to accept as it is with no regard to its management. Society does not generally consider expenditure in further reducing such risks justifiable.

Tolerable Risk – A risk that society is willing to live with so as to secure certain net benefits in the confidence that it is being properly controlled, kept under review and further reduced as and when possible.

2.2 General principles

A basic question regarding landslide risk acceptance is who should determine such acceptable risk levels. It is possible to provide some general principles and some information from other engineering industries. These can be used to obtain a general appreciation of the risks and to suggest some acceptance criteria for landslides. Nonetheless, the decision on risk acceptability (or tolerance) must be made by the client, owner, regulator and those at risk, where they are an identified group (Fell, 1994). This is supported by social science approaches which underline the role of social processes as decision-maker.

There are some common general principles that can be applied when considering tolerable risk criteria. These are taken from IUGS (1997):

- The incremental risk from a hazard to an individual should not be significant compared to other risks to which a person is exposed in everyday life;
- The incremental risk from a hazard should, wherever reasonably practicable, be reduced, i.e. the As Low As Reasonably Practicable (ALARP) principle should apply;
- If the possible loss of life from a landslide incident is high, the risk that the incident might actually occur should be low. This accounts for the particular intolerance of a society to incidents that cause many simultaneous casualties, and is embodied in societal tolerance risk criteria;
- Persons in the society will tolerate higher risks than they regard as acceptable, when they are unable to control or reduce the risk because of financial or other limitations;
- Higher risks are likely to be tolerated for existing slopes than for planned projects, and for workers in industries with hazardous slopes, e.g. mines, than for society as a whole;
- Tolerable risks are higher for naturally occurring landslides than those from engineered slopes;
- Once a natural slope has been placed under monitoring, or risk mitigation measures have been executed, the tolerable risks approach those of engineered slopes;
- Tolerable risks may vary from country to country, and within countries, depending on historic exposure to landslide hazard, and the system of ownership and control of slopes and natural landslide hazards.

In some situations risk may be tolerated because the individuals at risk cannot afford to reduce risk even though they recognize it is not properly controlled.

In theory it is desirable to establish such criteria and develop the F–N curve for landslide hazard. The F–N curve is a plot showing the number of fatalities (N) plotted against the cumulative frequency (F) of N or more fatalities on a log–log scale (Wong et al., 1997; Ho et al., 2000). Tolerable risk criteria also usually require that maximum involuntary risk of death to a single individual in a specified location should not exceed a specified threshold (Morgenstern, 1997). Establishing such criteria for landslide hazards should make use of existing data to construct F–N curves. The concept in each case would be to gather data on the frequency of landsliding causing fatalities or injuries, and analyzing this for the population of slope features, and the reaction of the public to the fatalities or injuries, and the measures taken by the owners of the slopes, or government authorities, to mitigate the risk (Dai et. al, 2002).

2.3 Proposed approaches

Regardless of the frequency of events, one method that may establish an upper threshold for the acceptability of landslide risk is to take into account the population’s reaction to high-intensity events. As an example, Wulong in Chongqing is well known for its high frequency of landslide disasters, which tend to be expensive events. Thus, the landslide disaster that occurred at Wulong on 1 May 2001 (the Wulong 5.1 landslide event, Fig. 1), which killed 79 people, produced a tremendous impact nationwide, aroused unprecedented coverage by the mass media and prompted new legislation on landslide hazard and risk-assessment procedures. The catastrophic event probably exceeded the threshold for acceptable landslide risk. Such a threshold may vary in time and from place to place, depending on social, economical and cultural factors. It can be compared with the consequences of car accidents, which on average kill an equivalent number of people every 2 weeks in China. In this respect, the Wulong event shows the difference between perceived and objective landslide risk levels, and how risk criteria are established on the basis of the number of people killed by slope movements.



Fig. 1. Panoramic view of Wulong ‘1 May’ landslide area

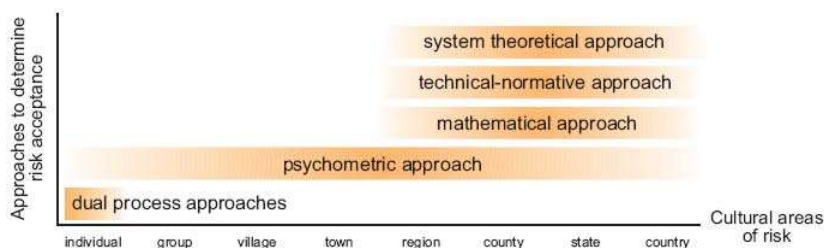


Fig. 2. Use of scale dependent definition of acceptable risk levels (after Bell & Glade, 2005)

Demands to guarantee a uniform safety level accepted by the public are increasing. But as discussed there might be differences from state to state, village to village, etc. Thus, new approaches and concepts might be necessary to find sound solutions for the challenge of determining acceptable risks. One possible solution might be the concept of the scale dependent definition of acceptable risk levels (Fig. 2). Whereas at a national scale acceptable risks might be defined by using the technical-normative approach or a mathematical approach (Plattner, 2005), at lower scales other approaches are needed. Fig. 2 shows that the psychometric approach is applicable at all scales. This only refers to how the approach is used currently.

3 SOME ESTABLISHED RELATED RISK CRITERIA

3.1 Risk acceptability criteria for dams

There are no established criteria backed by a Government for landsliding although various criteria have evolved and been adopted for example in projects such as dams.

The risk levels were defined by comparison with many other risks, e.g. the risk of fatality in a traffic accident, mortality rates for different age groups, other acceptable societal risks such as aviation and for workers in different industries. Risk aversion factors are introduced since natural risks are considered to be involuntary risks. Defined risk levels refer to individual risk to life. Three risk classes were implemented: high risk (C): $\geq 3 \times 10^{-4}$ / year; medium risk (B): 1 to 3×10^{-4} / year and low risk (A): 0.3 to 1×10^{-4} / year (Bell & Glade, 2005).

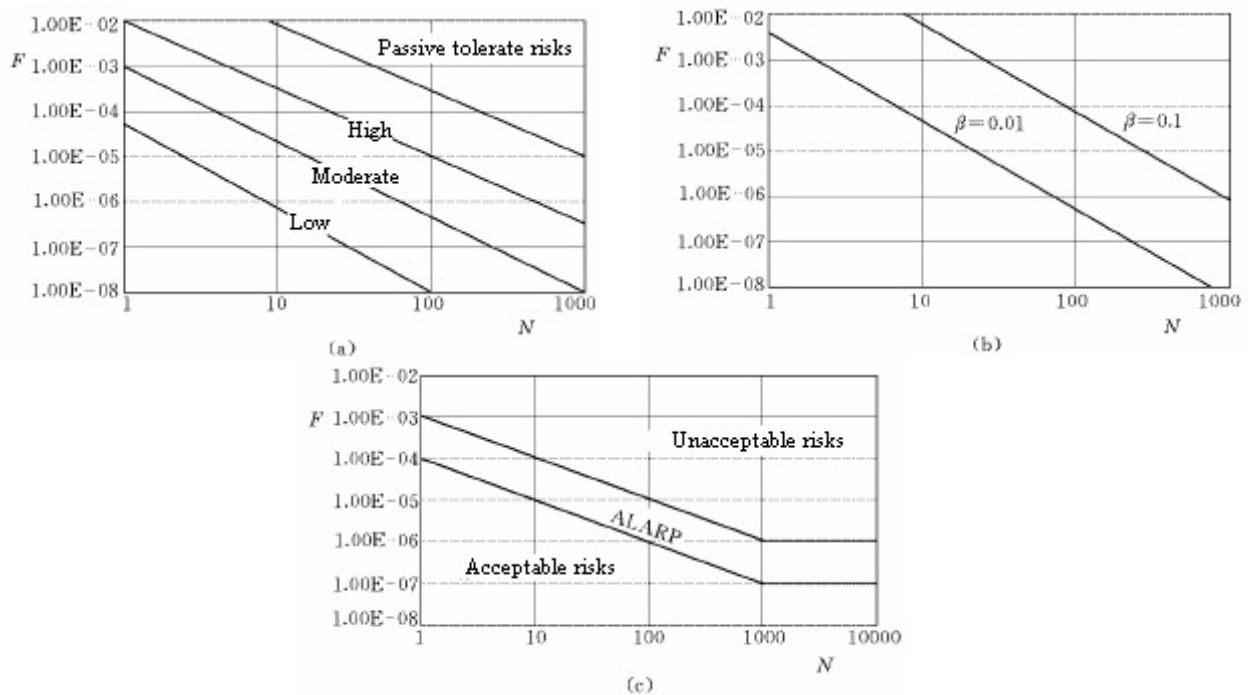


Fig.3. Tolerable risks of dam in some countries

(a) South Africa; (b) Holand; (c) Australia (Note: N refer to the number of failure dams)

3.2 The Health and Safety Executive in the United Kingdom

Risk tolerability criteria are integral parts of risk management because they serve as yardsticks for deciding whether the estimated risk is excessive or can be tolerated. The risk criteria framework adopted by many overseas countries, e.g. the Health and Safety Executive in the United Kingdom, consists of the following three regions :

- (1) Unacceptable region,
- (2) 'As Low As Reasonably Practicable' (**ALARP**) region, and

- (3) Broadly acceptable region (where the risk is, or has been made, so small that no further precaution is necessary).

3.3 Risk guidelines established in Hong Kong

Hong Kong is one of the leaders in the world in developing and applying QRA techniques to quantification and management of landslide risk. The Hong Kong Planning Standards and Guidelines give criteria on acceptable and unacceptable risk for PHIs. National standards have been produced in some countries, such as the United Kingdom, Australia, New Zealand and Canada, to provide general guidance on risk management and risk analysis.

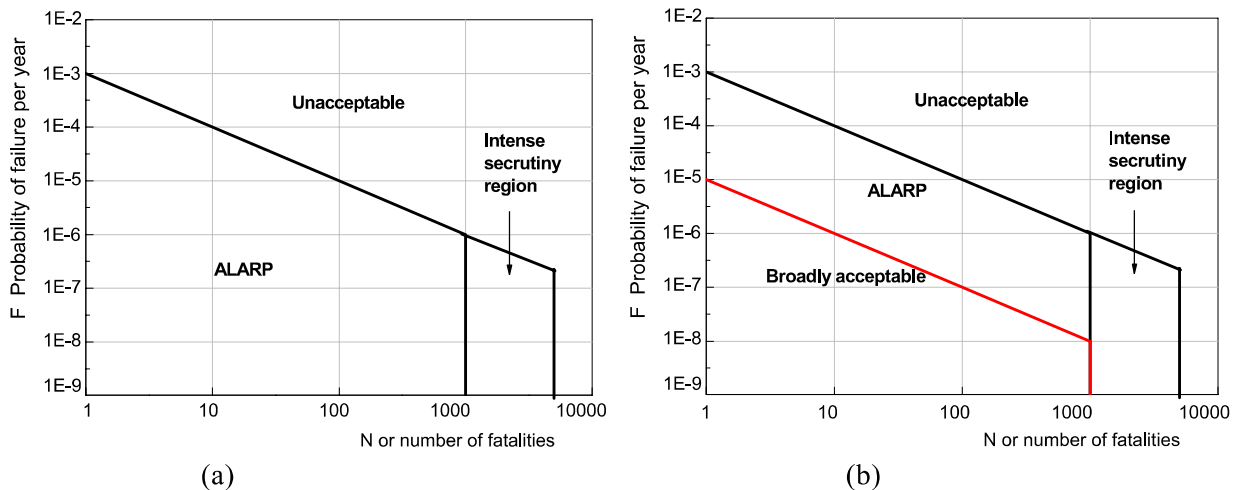


Fig. 4. Interim acceptable societal risk in Hong Kong set by Hong Kong government (a) preferred option; (b) alternative option.

However, there is as yet no international or national standard specifically for landslide risk assessment. Establishing appropriate risk criteria is by no means a scientific matter alone; in practice, this involves socio-political considerations. The interim societal risk criteria for natural terrain landslide hazards recommended by the GEO are shown in Fig. 4. Two options are available. They serve as a basis for the evaluation of QRA results. It is intended to finalize the risk guidelines after a period of trial use. In Hong Kong the Geotechnical Engineering Office proposed interim risk guidelines for landslides (from natural terrain) in 1997. Similarly acceptable risk levels were defined by comparison with other risk criteria (e.g. risk resulting from major hazardous installations, railways or large dams). The following risk levels were proposed to be acceptable: individual risk (per year) for new developments: max. $<10^{-5}$ / year; for existing developments: max. $<10^{-4}$ / year.

In addition acceptable risk criteria for societal risk (per year) was proposed relating the probability per year of an event causing N or more fatalities (F) to N (F-N curve). A maximum of 5000 fatalities in a single event is supposed to be tolerated if the probability (F) is low enough ($\sim 10^{-7}$ / year and less) – but only for specific types of developments (Geotechnical Engineering Office, 1997).

4 EVALUATION OF LANDSLIDE RISK

A prerequisite for establishing acceptable and tolerable risks are reliable risk analysis results. However, risks may vary heavily depending on different input parameters and models. So it's critical and necessary to evaluate landslide risk.

Although the number of deaths remains the most consensual measure of catastrophic event, the idea of using it as a proxy for landslide impact or intensity has definite limitations (Guzzetti, 2000). For example, some devastating landslides, caused no death, but its economic losses may be more than tens or hundreds of million. Merely in terms of casualties, these landslides would not have been regarded as a significant event, despite the very high levels of damage that it caused. Despite this

obvious limitation, careful analysis of a record of landslide fatalities may indeed provide reasonable estimates of landslide risk to human beings.

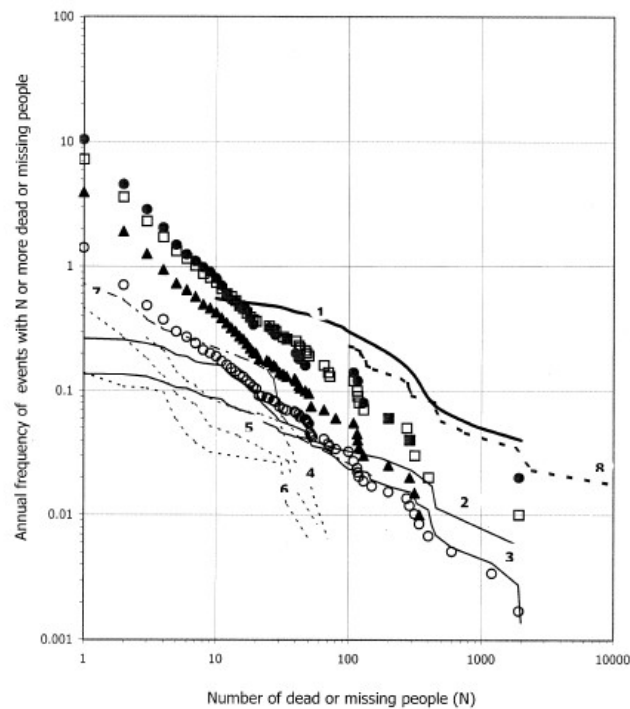


Fig.5. World-wide comparison of frequency vs. consequences (F–N plot) curves. 1: Japan (1948–1996); 2: the Alps (1800–1974); 3: the Alps (1248–1974); 4: Canada (1860–1996); 5: British Columbia (1860–1996); 6: Quebec (1840–1996); 7: Hong Kong (1948–1996); 8: China (1900–1987). (after Guzzetti, 2000)

In a risk analysis, it is common practice to plot frequency against consequences in F–N diagrams. In the case of landslides, F–N plots are graphical representations of the cumulative probability per year that the number of fatalities resulting from landslides, on a log–log scale (Fell and Hartford, 1997). The advantage of using F–N plots is that F–N curves are available for several types of disasters, which facilitates comparison of the effects of natural disasters with established or acceptable criteria for societal risk assessment. The curves of frequency against consequences for landslides that have caused deaths or missing people in China from 1900 to 1987 are shown in Fig. 5.

Moreover, Fig. 5 shows estimates of landslide frequency plotted against consequences for China together with similar data for Canada, the Alps, Japan, Hong Kong and Italy (Guzzetti, 2000). With a larger number of catastrophic events that result several tens or hundreds of deaths. It should be noted that the Chinese curve on events that caused at least 100 deaths. The higher number of low-intensity events (10 fatalities) recorded in Italy in comparison with the Japanese and Chinese curves, and the resulting larger frequency, reflects the incompleteness of the Japanese and Chinese catalogues for the low-intensity events.

5 PROPOSED ACCEPTABLE AND TOLERABLE LANDSLIDE RISK CRITERIA

Analyzing the breakage loss of landslide hazard from the abroad sense, it is composed of occurrence of different types of adverse consequences, such as the loss of life, economic loss, environmental loss and social loss (Table 1). A wide range of tolerance to risk and the risk criteria are only a mathematical expression of general societal opinion. So to establish landslide acceptable risk levels, firstly it needs to classify the variety risks and accordingly formulate the coincident risk criteria. It is advised to classify the four sorts of landslide risk that are risk to loss of life, economic risk, environmental risk and societal risk in China of the present stage (Li Lei, 2006).

Table 1. Effects and losses caused by landslide hazards

Types of Effects	Losses
Life effects	Death
	Injury and disability
	Psychosis and psychological injury
Economic effects	Destruction and losses of wealth
	Direct industrial losses (no production) Associated industrial losses (losses of overflow investment)
Environmental effects	Soil resource effects
	Integrated environmental effects

5.1 Risk criteria to loss of life

The loss of life should be the most serious losses. Not only the decedents lose their lives in vain, but also may make the survival psychological panic and astaticism of society, it's hard to quantify its impact using economy index.

It is common to classify the risk to loss of life to individual or societal risk to life. There are still no established individual or societal risk acceptance criteria for loss of life due to landslides in China or internationally. It is possible to provide some general principles and some information from other engineering industries, e.g. petrochemical and dams. These can be used to obtain a general appreciation of the risks and to suggest some acceptance criteria for landslides. Nonetheless, the decision on risk acceptability (or tolerance) must be made by the client, owner, regulator and those at risk, where they are an identified group.

Table 2. Proposed tolerable risk for loss of life

Situation	Crowd property	Suggested Tolerable Risk
Existing Slopes	person most at risk	10^{-4}
	average of persons at risk	10^{-5}
New Slopes	person most at risk	10^{-5}
	average of persons at risk	10^{-6}

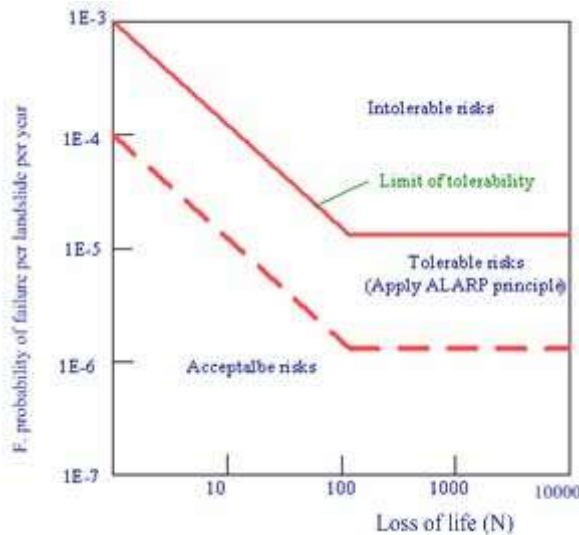


Fig.6. Proposed social risk criteria to life

For individual risk, in a review of the literature on risk assessment (ANCOLD, 2003; Fell, 1994), we can found that the most commonly acceptable level varies between a frequency of 10^{-5} and 10^{-6} per year for risk perceived as involuntary, to 10^{-3} – 10^{-4} per year for risk perceived as voluntary (Table 2). Such values can be compared with landslide mortality rates for mainland of China shown in Fig. 5. Regardless of the frequency of event, social risk criteria to life in the mainland of China is proposed in Fig. 6.

5.2 Economic (Property) risk criteria

Generally, reasonable thresholds for the acceptance of economic risk criteria is established according to the comparison of the economy loss of landslide resulted in and the develop level of social economy of the time.

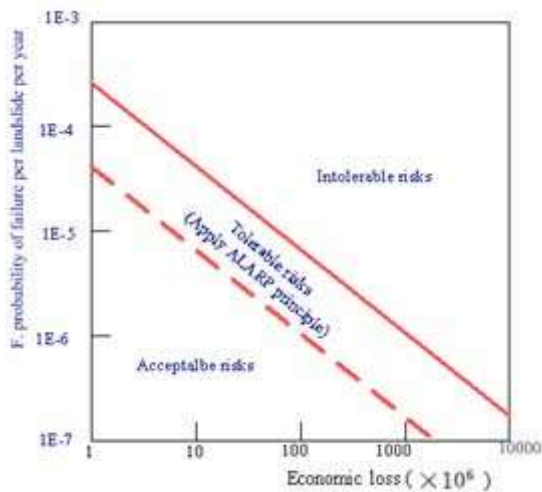


Fig.7. Proposed economic risk criteria of towns and cities of villages

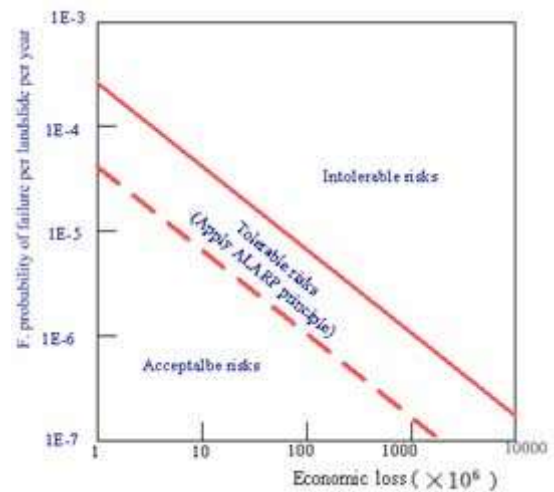


Fig.8. Proposed economic risk criteria

The develop level of economy vary from the towns or cities and villages in the mainland of China, so it should consider the unbalance of the economic development and according to develop level of economy and tolerate ability to the economic risk in different regions and then establish economic risk criteria of landslides respectively.

Referred to the economic risk criteria defined by ANCOD & B. C Hydro (2003) and compared with the economic development of Australia and Canada, the proposed economic/property risk criteria in the mainland of China are shown in Fig.7 and 8.

5.3 Environmental risk criteria

So far, there are no established environmental risk criteria in China or internationally for it is a hard and uncertain operation to quantify the environmental loss caused by landslides with money. Generally speaking, the landslide volume and travel distance are the main decisive factors. Hence, the environmental risk criteria can be established in terms of the probability of landsliding which is governed by the damage potential index D defined by (Fig. 9 and 10).

$$D = V \times L$$

Where, D refers to the damage potential index, m^4 ; V refers to the landslide volume, m^3 ; L refers to the travel distance of landslide, m .

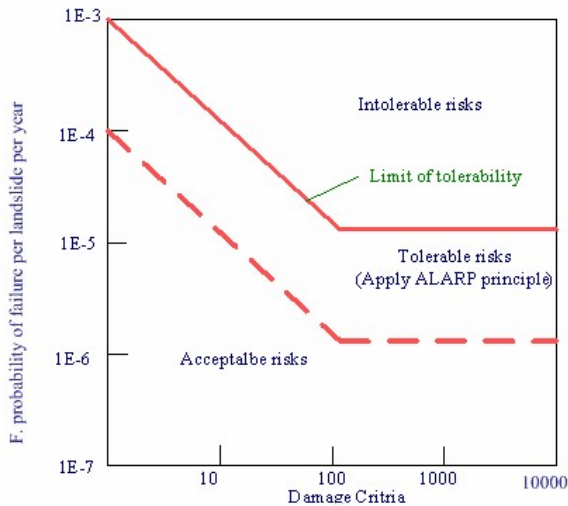


Fig. 9. Proposed ecotypic environment risk criteria

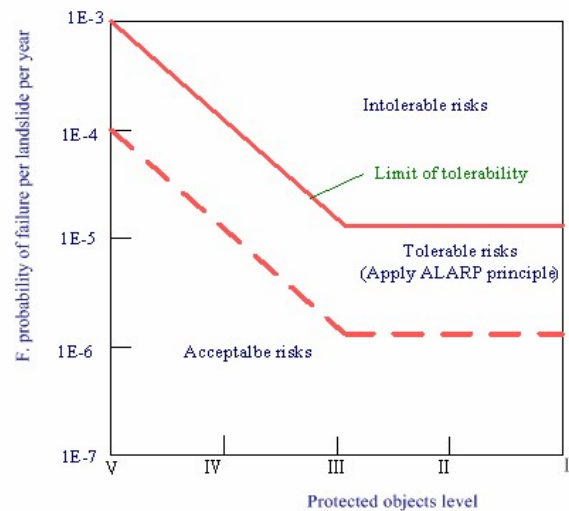


Fig. 10. Proposed humanism and natural environment risk criteria

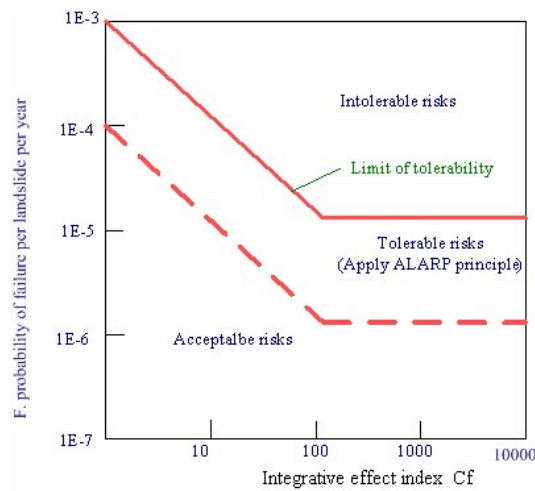


Fig. 11. Proposed humanities and environmental risk criteria

5.4 Social risk criteria

In the developed countries, great social risk generally will not be caused because of comparatively more perfect of the emergency mechanism to paroxysmal affairs, the insurance system and the national indemnity system for risk. While that of China is reverse. China is being placed in the primary stage of the social development, the risk management system, the emergency mechanism to paroxysmal affairs, the insurance system and the national indemnity system are not sound. So once suffering high-intensity events, conflict of society were easily to arouse, and even endanger the social stabilization. Hence, it's essential to research and establish reasonable social risk criteria.

When establishing societal risk criteria, an upper limit is often established for acceptable risk in relation to the number of expected casualties, regardless of the frequency of event. The method that helps to establish an upper threshold for the acceptability of landslide risk is to take into account the population's reaction to high-intensity events.

Societal risk criteria for China were defined in Fig. 11 and can be compared with similar acceptable societal risk criteria available in the literature (Fell & Hartford, 1997). Landslide criteria for the mainland of China are about three orders of magnitude higher than the criteria proposed for man-made structures. However, these risk levels are at the stage of discussion and will be tested in case studies and modified if necessary.

6 APPLICATION OF THE CRITERIA

As above presentation, Wulong in Chongqing is well known for its high frequency of significant landslide disasters occurred customarily during major rainstorms from May to August. The QRA of another catastrophic landslide called ‘5.8 Government Landslide’ of Wulong in Chongqing may be a typically application (Fig. 12).

This landslide is 300 m long, typically sloping at 65°-80°, and has area of about 290,000 m² and a volume of about 630m³. It is mainly a fill slope overlying the mudstone/sandstone bedrock and some composed of soft clay overlain highly fractured rock mass. The fill body is composed of clayey sand with a mixture of gravel, had a history of instability. It was formed in 1993 from uncontrolled dumping during the construction of the nearby highway and buildings. Every year, during heavy rainy season, the fill saturates with water and moves. The decade record shows that it has moved by 60–80 mm and settled at 130 mm in 8 May 2005, it had moved by 20–30 mm and cracks were developed inside the fill body and extended upward. Several houses close with the slope developed cracks, threatening the lives of more than 8000 people. Remedial works were carried out in 2005 and launched into more than 10 million RMB.



Fig. 12. Panoramic view of Wulong ‘5.8 Government Office Landslide’ in Chongqing, China

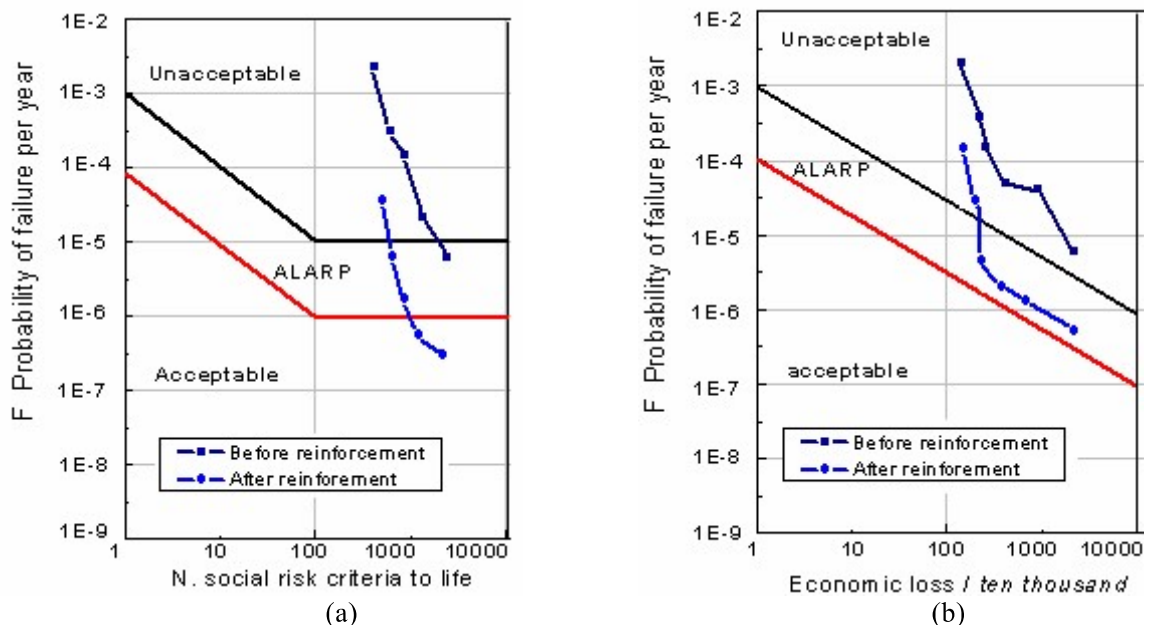


Fig. 13. Calculated risk compared with the acceptable or tolerable risk for the ‘5.8 Government Office Landslide’ before and after carried out reinforcement. (a) social risk to life; (b) economic loss.

By integrating the hazard model, frequency assessment and consequence assessment, risk levels to loss of life and economic loss at different locations were computed and contoured. The site-specific risk acceptance criteria were determined through a review of different risk acceptance criteria and consideration of the situation involving Wulong Government Office.

The results of the QRA indicated that a large area of the squatter area fell within the unacceptable region in terms of individual risk. The assessed societal risk was also found to be unacceptable (Fig. 13). Risk calculations further showed that the typical options and methods for treating the risk would include reduce the likelihood which would require stabilisation measures to control the initiating circumstances, such as reprofiling the surface geometry, groundwater drainage, anchors, stabilising structures or protective structures etc, and reduce the consequences which would require provision of defensive stabilisation measures, amelioration of the behaviour of the hazard or relocation of the development to a more favourable location to achieve an acceptable or tolerable risk (Wong, 2006). After implementation, the risk should be acceptable or tolerable, consistent with the ALARA principle.

This is a useful example, which could have been readily quantified for loss of life and damage, and hence enabled evaluation relative to acceptance criteria rather than simply accepting “No risk” (ERM, 1998; Hardingham, 1998).

7 DISCUSSION AND CONCLUSIONS

The accepted risk level of landslide hazard sometimes vary in time and from place to place, depending on social, economical and cultural factors. So to establish reasonable thresholds for the acceptance of societal risk (i.e. the risk imposed on society) and individual risk (i.e. the risk imposed to any identified individual) is a difficult, intrinsically uncertain operation because of the different perceptions of all involved parties. It can be compared with the consequences of car accidents, which on average kill an equivalent number of people every a period of time.

Acceptable and tolerable risk criteria for landslide hazards in the mainland of China were defined. Such criteria can be compared with similar acceptable and tolerable societal risk criteria available in the literature (Morgan, 1991; Evans, 1997; Fell and Hartford, 1997; Dai et. al, 2002). It is strongly recommended, however, that the societal risk criteria should not be mandatory, and should be used as guidelines only. The need for new concepts and new approaches is also stressed by the following statements. Decision makers, however, need to understand how people think about and respond to risk. Otherwise well intended policies may be ineffective. These suggested criteria are targeting primarily at skilled practicing geotechnical professionals. We are expecting that more completed and rational criteria will be established for Slope Assessment and presented in a format more readily used by owners and regulators.

There are some problems in defining and applying acceptable landslide risks. First, as already discussed it is not trivial to define the acceptable risk levels reliably that can reflect the risk accepted by the threatened people. Second, the risk values resulting from risk analysis must be reliable and third, the defined acceptable risk levels must somehow be comparable to the calculated landslide risk values.

Finally, due to the variation of risks and the acceptance of risks in space and over time rather dynamic approaches instead of static approaches to analyzing risks and defining acceptable risk levels are needed.

From all the above analyses, we can make a conclusion that quantitative risk assessment and risk management of landslide are new to many, and it is a developing art.

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