COMPARATIVE RISK INDICATORS & POSSIBLE CLIMATE CHANGE TRENDS IN HONG KONG AND IMPLICATIONS FOR THE SLOPE SAFETY SYSTEM

GEO REPORT No. 128

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THE GOVERNMENT OF THE HONG KONG SPECIAL ADMINISTRATIVE REGION

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PREFACE

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. A charge is made to cover the cost of printing.

The Geotechnical Engineering Office also publishes guidance documents as GEO Publications. These publications and the GEO Reports may be obtained from the Government's Information Services Department. Information on how to purchase these documents is given on the last page of this report.

R.K.S. Chan
Head, Geotechnical Engineering Office
October 2002

EXPLANATORY NOTE

This GEO Report comprises a Special Project Report and a Technical Note on two separate research and development projects carried out by the Special Projects Division in 2001.

The reports are presented in two separate sections in this GEO Report. Their titles are as follows:

SECTION 1: COMPARATIVE RISK INDICATORS

H.W. Sun & N.C. Evans

This report was originally produced in January 2001 as GEO Special Project Report No. SPR 1/2001

FOREWORD

This Report reviews the use of risk indicators as part of the risk assessment process. It examines the possible implications of using different types of risk indicator for the various types of risk assessment carried out by the GEO. The study derives from a recommendation by the Slope Safety Technical Review Board that the use of nominal risk indicators be considered.

The Report was first circulated within GEO as a draft Discussion Note, in November 2000. A wide spectrum of comments and suggestions were received, and the report was revised and expanded to a Special Project Report.

The study was carried out, and the report written, by Dr H.W. Sun and Mr N.C. Evans of Special Projects Division. Many colleagues in GEO provided valuable comments on the original draft.

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ABSTRACT

This Report reviews the use of risk indicators as part of the risk assessment process. It examines the possible implications of using different risk indicators for various types of risk assessment.

Risk assessment involves a combination of analytical methods and consideration of social factors, and is best regarded as a framework within which informed decisions can be made. Quantitative Risk Assessment (QRA), comprising the calculation of risk numerically and comparison with various criteria, can form part of this process but it is not necessarily the most important part.

Risk assessments using calculated risk are usually based on probability of death. However, studies on the public perception of risk have highlighted its multi-dimensional and subjective social value aspects.

Risk, especially calculated risk, is a measure of the effect of a hazard on a susceptible population. Very few risks are distributed evenly. This can be referred to as risk "clustering". The implications of clustering need to be considered when comparing different types of risk.

Risk acceptance criteria are controversial. Decisions made based solely on these criteria are placing very high reliance on both the reliability of the risk analysis and the suitability of the risk indicator for the required purpose. There is no clear consensus on how such criteria could be applied in different situations. The issue of cumulative risk does not appear to be satisfactorily addressed anywhere.

Risk assessment should be iterative and consultative. Attempts should be made to integrate social perceptions with calculation in the risk assessment process. When calculating risk, the risk indicator chosen, and the way in which it is calculated, should be determined by the nature of the decision which is to be made. Decisions should not, however, be made solely on the basis of calculated risk or cost/benefit analyses.

Social perceptions of risk do not necessarily agree with objectively assessed risk. In Hong Kong, social perception of risk appears to be governed by a reasonably well-informed opinion of the probability of an individual's exposure to that risk.

CONTENTS

1. INTRODUCTION

This Report reviews how risk indicators can be developed and presented in different ways, and discusses this in the context of various types of risk in Hong Kong, including risk from landslides. Some suggestions are proposed for possible ways forward in the use of risk assessment approaches and techniques within the Slope Safety System. The intention of the Report is to draw attention to the various issues concerned.

Risk assessment in the broad context involves a combination of analytical methods and assessment of social values, and is not totally amenable to the application of the physical scientific methods or design processes with which engineers tend to be familiar. It is, rather, a framework within which an iterative process can take place with the intention of making informed decisions. Quantitative Risk Assessment (QRA), comprising the calculation of numerical risk and comparison with various criteria, can form part of this process, but it is not necessarily the most important part.

Slovic (1999) summarises the current position of risk management as follows. *"Risk management has become increasingly politicised and contentious. Polarised views, controversy and conflict have become pervasive. Research has begun to provide a new perspective . . . by demonstrating the complexity of the concept "risk" and the inadequacies of the traditional view of risk assessment as a purely scientific enterprise . . . Risk assessment is inherently subjective and represents a blending of science and judgement with important psychological, social, cultural and political factors."*.

2. "CALCULATED RISK" AND "PERCEIVED RISK"

2.1 General

There are methodological and disciplinary divisions between risk researchers, scientists, engineers and lay people in their understanding and perceptions of risk. Risk assessments using "calculated risk" are usually based on one single measure of risk. On the other hand, studies on the public perception of risk have highlighted the multi-dimensional aspects and the subjective social value elements of risk. It is important for regulators and decision-makers to understand and consider these aspects of risk so that the needs of the public can be properly addressed.

It is possible to obtain a "calculated risk" using a number of different analytical techniques. There are problems with this approach. Calculation of risk is itself subject to many uncertainties and to (sometimes hidden) value-laden judgements concerning the relative importance and applicability of different risk indicators. "Calculated risk" usually takes no account of the nature of the risk and the demographics of the affected population. Finally, there can be communication problems and lack of understanding when discussing "calculated risk" with the various parties involved in decision-making. These problems are discussed in more detail below.

2.2 Uncertainty

Stern & Fineberg (1996) discuss uncertainty in risk assessment in some detail. Their views are summarised here as follows. Risk characterisations often give misleading information about uncertainty in several ways. They may give the impression of more scientific certainty or unanimity than exists (or the opposite); they may suggest that uncertainty is a matter of measurement when in fact it is a subject of judgement and disagreement; and they may give the impression that certain risks do not exist when in fact they have not been considered. Many risk characterisations still present point estimates of risk, representing these as upper-bound estimates and providing little or no analysis of the extent of overestimation. In spite of the obvious shortcomings of point estimates, alternatives (such as probability distributions) have not yet gained widespread acceptance by regulatory agencies and decision-makers. The problem of summarising uncertainty may have no technical solution.

It is therefore important to declare the approach adopted in the characterisation of risk, and what is known of the associated uncertainty, when the risk results are communicated to the decision-makers or the concerned parties. Some of the early applications of QRA to landslide and boulder fall hazards in Hong Kong adopted a point-value "best-estimate" approach, without due regard for the uncertainties involved.

Uncertainty commonly surrounds the likelihood, magnitude, distribution and implications of risks. Uncertainties may be due to random variations and chance outcomes in the physical world. These are known as "aleatory" uncertainties and might, when assessing landslide hazards, include rainfall distribution, progression of weathering, or accidental occurrences such as burst water pipes. Uncertainties also arise from a lack of knowledge. These are referred to as "epistemic" uncertainties, and, in the context of landslide hazard, might include inadequate ground or stability analysis models, or the incorrect or inappropriate application of analytical techniques. Sometimes, analysts may not know which model of a risk-generating process is applicable - this is known as indeterminacy.

An example of indeterminacy arose from recent studies of landslide hazard and risk from natural terrain (HAP, 2000). During these studies, two models of possible future landslide frequency were developed, one based on regional trends relating to slope characteristics (which may not always apply at individual sites), and the other on site-specific observed landslide frequency (which may be significantly affected by occasional extreme but localised rainfall events). The two models differed significantly in their prediction of possible future landslide frequency, and there is no way of telling which will be more accurate for any particular site.

When uncertainty is present but unrecognised it can be called simply ignorance. Where uncertainty is recognisable and quantifiable the language of probability can be used. Objective or frequency-based probability measures can describe aleatory uncertainty associated with randomness. This approach was used to manipulate statistics of landslide frequency, magnitude and behaviour during the recent studies of natural terrain discussed above (HAP, 2000). The approach was found to be workable for those types of landslides for which a substantial database of past events was available, and resulted in the calculation of risk parameters with associated bands of uncertainty rather than point values.

Subjective probability measures (based on expert opinion) can describe epistemic uncertainties associated with lack of knowledge. This approach has potential for addressing hazards for which there are insufficient data of previous events to construct mathematical probability distributions. This may be relevant when considering high magnitude/low frequency events such as large natural terrain landslides or debris flows. Expert opinion may also have a useful role to play if the probability of failure of man-made slopes is examined and there are insufficient data to carry out a statistical analysis of historical failure frequency. However, all such assessments need to be kept under constant review to ensure that they reflect the current state-of-the-art with respect to both available data and understanding of the processes involved, and the associated uncertainties should always be recognised.

Sometimes uncertainty is recognised but cannot be measured, quantified or expressed in statistical terms. In cases such as these, all that can really be done is to examine various possible hazard scenarios and subjectively rank them in terms of probability and consequence.

Morgenstern (1995; 2000) also discusses the different types of uncertainty with respect to geotechnical engineering and risk analysis, and emphasises the important role of qualitative analyses in the risk assessment process.

2.3 Multi-dimensional Nature of Risk and Risk Measures

Risks are measured in terms of the degree of harm that they may cause to society, organisations or individuals. Harm can be assessed in different ways. Measures of harm can include deaths, injuries, other health hazards, lost of production time, economic loss, inconvenience to individuals, socio-political disruption, environmental damage, etc. The choice of a particular measurement unit (the most usual is number of deaths) implies that we place particular value on that indicator. Social value and perception of risk are discussed further in Section 2.5.

Stern & Fineberg (1996) discuss the difficulties in choosing risk measures. They consider that the choice of measure can make a big difference, especially when one risk is compared to another. To properly characterise risk it may be necessary to use more than one measure. All measures are value-laden. Even a simple measure such as number of deaths embodies its own values, making no distinction between age of individuals or nature of death. Risk characterisation often focuses on a single outcome, most often human fatalities, but risk is multi-dimensional and even a single outcome can have multiple attributes. The general problem is how to characterise what is known about a risk when there is no clear way to combine its many attributes into a single measure.

One option is to reduce different risk attributes to monetary terms, enabling a total risk "cost" to be derived. Such an approach would require monetary value to be placed on certain non-monetary outcomes, such as death, injury, inconvenience, distress or environmental damage. While techniques exist for doing this, they are inevitably subjective and controversial. Cost/benefit analysis is considered further in Section 2.6.

2.4 Hazards and Susceptible Populations

Risk, especially calculated risk, is a measure of the effect of a hazard on a susceptible population. When calculating risk it is necessary to be very clear about how the population through which the risk is distributed has been defined. For instance, in a population such as that in Hong Kong, it may be reasonable to assume that risks from certain medical conditions are distributed relatively evenly through the entire population. In such a case as this it is, at first sight, eminently reasonable to calculate a "global" risk in terms of susceptibility or mortality rates divided by the entire population. If the risk applies to all equally, this "global" risk will be a fair reflection of the "individual" risk.

In reality, very few risks are distributed evenly. Even diseases or medical conditions to which all are exposed will tend to affect subsets of the population in different ways (depending on age, sex, habits, wealth, etc). To take an extreme example, a small number of individuals may be highly exposed to an unusual risk, possibly as a result of their occupation. If the associated mortality rates, or other measures, are divided amongst the entire population, it will mask the fact that the risk is actually concentrated on a few individuals whose level of risk may be extreme. This can be referred to as risk "clustering".

Risks can be clustered geographically, such as for a Potentially Hazardous Installation (PHI) with a clearly defined radius of possible impact (QRA was originally developed for such industrial installations with clustered risk); societally, with individuals voluntarily engaging in hazardous occupations or activities or involuntarily exposed to above-average levels of risk due to poor housing, lack of education, restricted career choice, etc; or temporally, i.e. some hazards materialise only occasionally, but could affect anyone in a given population - the extreme example would be a meteorite strike! Conversely, risks within a given population can be geographically diffuse, societally ubiquitous and temporally relatively even. Possible examples are traffic accidents and medical conditions such as cancer.

Between these extremes there is, of course, a continuum leading to an almost infinite range of hazard and risk characteristics. It is very important that these factors are considered when calculating risk, communicating the results, and comparing risks from different hazards.

If landslides and boulder falls are considered, the position with respect to clustering is not straightforward. Different types of slope failure have different clustering characteristics. For instance, the risk from large channelised debris flows is geographically clustered in streamcourse mouths, temporally clustered during rainstorms and, possibly, societally clustered in that those living in potential run-out zones in flimsy structures are most at risk. Conversely, risk from failed man-made slopes may be more diffuse both geographically and societally. Temporal clustering might also be more diffuse as these events do not always occur during rainstorms (leaking water services, construction, etc, also trigger these events). Risk from open-slope natural terrain landslides and boulder falls might fall between the two in terms of clustering. Figure 1 shows a possible way of illustrating graphically the relative clustering of different types of risk.

When calculating risk from landslides and boulder falls it is necessary to consider whether or not it is appropriate to average the risk over the whole population, or to calculate the risk to the population which is affected. There is no definitive answer to this, as the most appropriate parameter will depend, to some extent, on the particular requirements of a given risk assessment, i.e. what decisions are being made and why the risk assessment is being carried out.

In terms of clustering characteristics, large channelised debris flows appear to share some properties with PHIs (primarily the concentration of the hazard location and the population at risk). Open slope natural terrain landslides and man-made slope failures seem to be clustered somewhere between construction accidents and fire/traffic accidents with respect to geographic distribution and population at risk. The implications of these different types of clustering need to be considered when comparing different types of risk, or when faced with the task of choosing the most appropriate type of risk analysis.

2.5 Social Values

The above discussion relates to the assessment of calculated risk. However, as mentioned earlier, there is a further dimension to risk assessment which relates to social values. Social theory states that people tend to emphasise qualitative rather than quantitative aspects of hazard and risk. Their individual views are coloured by personal experience, belief, the media, and local culture, and they may be naïve or irrational. Even if this is the case, such views cannot be ignored. Removing an irrational but feared risk can improve an individual's quality of life.

Individuals tend to place a higher priority on hazards which they regard as catastrophic. Stern & Fineberg (1996) discuss this as follows. People tend to perceive a risk as higher when it evokes perceptions of dread, uncontrollability and catastrophe, and they want to see strict regulations to control such risks. Specialists in risk analysis instead tend to see riskiness as synonymous, especially for policy purposes, with expected annual mortality, consistent with the ways that risks tend to be characterised in QRA.

Baron *et al* (2000) report the findings of a survey on risk perception which compared "experts" and "non-experts". This work found that the two groups did not differ much in what determined their worries or their desire for action, but they did differ in their beliefs about particular risks. "Experts" tended to be more concerned about mundane but statistically frequent events such as traffic or domestic accidents, while "non-experts" were more concerned about statistically smaller risks from events such as cancer. This may be a result of inflated worry due to anticipated "dreadful" consequences, possibly exacerbated by media coverage which tends to focus on "newsworthy" rather than everyday events.

Citing statistics of "actual risks" often does little to change peoples attitudes and perceptions. Non-specialists factor in complex, qualitative considerations including judgements about uncertainty, dread, catastrophic potential, controllability, equity and risk to future generations. Stern & Fineberg quote the US National Research Council (1989:52) as follows:

"Those quantitative risk analyses that convert all types of human health hazard to a single metric carry an implicit value-based assumption that all deaths or shortenings of life are equivalent in terms of the importance of ignoring them. The risk perception research shows not only that the equating of risks with different attributes is value laden, but also that

the values adopted by this practice differ from those held by most people. For most people, deaths and injuries are not equal - some kinds of circumstances of harm are more to be avoided than others. One need not conclude that quantitative risk analysis should weight the risks to conform to majority values. But the research does suggest that it is presumptuous for technical experts to act as if they know, without careful thought and analysis, the proper weights to equate one type of hazard with another. When lay and expert values differ, reducing different kinds of hazard to a common metric (such as number of fatalities per year) and presenting comparisons only on that metric have great potential to produce misunderstanding and conflict and to engender mistrust of expertise."

A pilot study based on a small (34 people) sample was carried out by Hong Kong University (HKU, 1998) specifically to investigate the perception of landslide risk in Hong Kong. The study investigated the perceived characteristics of fifteen hazards in Hong Kong. Figure 2 shows the perceived riskiness of the 15 hazards from their focus group survey. The authors compiled a chart similar to that of Stern & Fineberg (1996) in which hazards are rated into four quadrants based on known/unknown and non-dread/dread. Cancer and nuclear power station accidents produce the highest dread. At the other extreme, bicycles and sunbathing are least dreaded. Cancer and active smoking rank as least known.

The three characteristics which have highest correlation (correlation factors between 0.7 and 0.9) with the riskiness ratings are personal exposure, voluntariness or risk and exposure of Hong Kong people. Other factors with less significant correlation (correlation factors between 0.6 and 0.7) are dread, control over risk, ease of reduction and equity.

Landslides occupy a similar position to fire, traffic accidents and construction accidents with respect to perceived knowledge. Landslides are very close also to fire in degree of dread (higher than traffic or construction accidents). This would seem to suggest that, from a societal point of view, the comparison of landslide risk with risks from fire, traffic accidents and construction accidents may be justified. Note however that construction accidents tend mainly to affect workers, making this a partly voluntary risk (although, as discussed earlier, social factors may force individuals to accept work which carries risk, and whether such risk can then be regarded as voluntary is arguable). As discussed earlier, any such comparison should also consider the clustering of the particular hazard and any subset of the population with above (or below) average risk.

The HKU study also found differences in hazard perception between different groups of people - age, religion, etc, may be factors. So the characteristics of a given population (or subset) could be a factor in determining their concerns. The study also investigated the tolerability of risk. An interesting finding was that the pilot study sample considered landslide risks to themselves could be increased slightly and would still be tolerable, whereas risk to Hong Kong society as a whole should be decreased. By comparison, the sample felt that risks from traffic accidents and occupational accidents should be decreased for both themselves and for Hong Kong society as a whole. Of course, the sample size is small, and different results could be obtained if a subset of the population living close to a large and apparently dangerous slope was studied.

Another interesting finding was that people thought about death, traffic jams and accidents, transport inconvenience and loss (both economic and time) when they considered "landslides". This suggests that measuring landslide (and other) risks simply by the number of deaths may not always be adequate (see also Section 2.3).

The HKU study group felt that fire and flooding were similar to landslides in terms of severity of consequence and the large amount of money required to prevent their occurrence. More people considered themselves to be at risk from fire, hence this was considered riskier than landslides. The study group preferred to see money spent on preventing a single catastrophic accident rather than on a chronic risk producing the same number of deaths. Their response was not entirely rational as the same group also considered the chronic risk to be worse as more people were exposed to it.

This seems to indicate that the study group considered the prevention of one landslide with big consequences to be preferable to the prevention of lots of small ones with less severe consequences.

Figure 3 shows the ranking of perceived riskiness from the HKU survey as related to an assessment of the risk clustering. This very interesting plot seems to suggest that public perception of risk is very much related to risk clustering, i.e. the more diffuse a risk (and therefore the more chance of it affecting the individual) the greater the public concern.

2.6 Risk "Acceptability" and Cost/Benefit Analysis

One of the outcomes of analytical (quantitative) risk assessment is the definition of "acceptance criteria", usually based on a statistical evaluation of risk-to-life. Such criteria tend to be phrased either as Individual Risk (IR), i.e. probability of death for an individual per year, or Societal Risk. Societal risk is usually represented as a plot on a graph of Frequency (of incident per year) against Number of deaths per incident. This is known as an F-N curve. Various attempts have been made to define whether a given F-N curve represents an "unacceptable" risk. A common refinement is the definition of a zone of intermediate risk referred to as ALARP (a statement that risks in this zone should be reduced to a level which is As Low As Reasonably Practicable).

The position of acceptance criteria within a decision-making process can be controversial. Decisions made based solely on these criteria are placing very high reliance on both the reliability of the risk analysis and the suitability of the risk indicator for the required purpose. There is no clear consensus on how such criteria could be applied in different situations. The issue of cumulative risk (either from multiple developments or individuals exposed to a single hazard, or to a single individual or development exposed to multiple risks) does not appear to be satisfactorily addressed anywhere. The following discussion raises some of the issues involved.

The Health and Safety Executive (HSE) in the UK and the NSW Planning Department (NSWPD) discuss the possible use of criteria for land-use planning in the vicinity of major industrial hazards, as cited by ERM(1998) and Fell & Hartford (1997).

For members of the public living close to a nuclear power station or a major hazard facility (note the definition of the susceptible population), the HSE defines individual risk criteria of 10^{-4} & 10^{-6} per year respectively for the upper and lower bounds of ALARP. Above the upper bound, risk is considered to be substantial and below, negligible. Note that these are not probabilities of death but the probability of receiving a “dangerous dose” which would result in death. The probability of death is about 10^{-1} for a person receiving the “dangerous dose”.

The HSE do not recommend “formal” societal risk criteria in a decision making process. To quote their report -

“there is at present no clear consensus on criteria for societal risk, and it is not even clear how best to describe such risk. The F-N curve is a difficult concept, and it is not apparent how to compare two F-N curves for two different situations...”

“a societal risk is (clearly) *below a criterion F-N line if the whole F-N curve is below the line, but it is not obvious when* (only) *part of the curve crosses the line.”*

“another difficulty for the present purpose is that developments are considered one at a time, and the contribution to the total national societal risk from any one development is very small. Even at local level, the additional societal risk from a small development in a built-up area may seem small... However, over the years the small additions to societal risks will accumulate, and eventually it will appear that there has been a considerable increase in the number of people at risk from major hazards.”

The HSE consider societal risk in a simplified way in view of these difficulties. Their advice is based on criteria for individual risk with societal risk allowed for by using more stringent criteria for larger developments. The HSE consider a risk “substantial” and will recommend against housing developments if there is individual risk of 10^{-5} per year for more than 25 people receiving a dangerous dose, or if there is an individual risk of 10^{-6} per year for more than 75 people receiving a dangerous dose. Allowing for differences in temporal occupancy of the different categories of development, the HSE derived equivalencies in consideration of societal risk.

The NSWPD has derived detailed individual fatality risk criteria for various land uses, e.g. medical facilities, schools, residential, commercial, sports, industrial, etc. For residential development, the individual fatality risk limit is 10^{-6} per year. The variation of the criteria considers different vulnerabilities of people in different types of facilities. It also has a higher level of acceptable risk for industrial areas, reflecting the voluntary aspect of risk acceptance criteria. They suggested a qualitative approach be used for assessing societal risk, because of difficulties in applying F-N curves.

A corollary of calculating risk analytically is that it is theoretically possible to carry out cost/benefit analyses for different types of mitigation. This can be done by comparing the cost of a particular measure to the reduction in risk achieved. This can be particularly pertinent for projects falling in the ALARP region. Theoretically, if a cost is assigned to an individual life, it is possible to calculate how much money could or should be spent to reduce a risk to an acceptable level. This is another way of analysing whether a project is viable or not. The drawbacks to this approach are the same as the drawbacks with all such analytical techniques, i.e. the uncertainties in the analysis have to be faced and the appropriateness of the risk indicator has to be considered. A further factor is that such a process can be considered to be extremely “cold-blooded” and might offend those concerned. Stern & Fineberg (1996) quote Arrow et al, (1996) as follows:

"Benefit-cost analysis is neither necessary nor sufficient for designing sensible public policy. If properly done, it can be very helpful to agencies in the decision-making process there may be factors other than benefits and costs that agencies will want to weigh in decisions". Care should be taken to assure that quantitative factors do not dominate important qualitative factors in decision-making."

Cost/benefit analysis can, however, help to demonstrate how effective different types of risk mitigation measure might be, i.e. which method provides most risk mitigation for a given sum. Again, such analyses should be carried out carefully with due consideration given to all the factors involved.

3. COMPARATIVE RISKS

Figure 4 shows some statistics on fatalities in Hong Kong. Statistics on multiple fatality events in Hong Kong are plotted as F-N curves in Figure 5. If we are to rank risks in terms of simple human fatalities per unit of population, these diagrams may be acceptable. However, as discussed above, risks are both multi-dimensional and clustered (to different degrees) and it can be misleading to compare one calculated risk with another unless they are similar in these respects.

As an example, Figure 4 shows that the annual fatalities from trench collapses and landslides in Hong Kong have been, over the last ten years, very similar. However, there are many differences between these two hazards. The population at risk from trench collapses is orders of magnitude lower than that at risk from landslides, suggesting that the individual risk within the affected population is much higher. This is not the only difference. It could be argued that the potential for casualties from landslides (in the absence of government regulatory procedures and mitigation/improvement works) is considerable, whereas that from trench collapses is limited. The voluntary/involuntary risk factor also has to be considered. So two hazards which, at first sight, have very similar basic casualty statistics, cannot be treated in the same way.

Figure 6 compares some Hong Kong average annual fatality numbers with the perceived riskiness ratings as found in the Hong Kong University survey. There is no obvious correlation between these two measurements, except that the riskiness rating for hazards causing annual average fatalities of more than ten are relatively high. The HKU report concluded that subjective risk or risk perception is not solely determined by the number of deaths. As discussed in Section 3, perceived riskiness appears to be very much related to the clustering of the hazard and the resulting probability that an individual will be exposed to that hazard.

4. WAYS FORWARD

4.1 Risk Assessment Process

Stern & Fineberg (1996) define good risk characterisation as that which meets the needs of decision participants, and draw the following conclusions.

Risk assessments should be accurate, balanced and informative. The authors state "get the science right and get the right science". The heavier the reliance on underlying assumptions, the greater the need for wide participation in the risk decision process. While various statistical and analytical techniques, and techniques for estimating and representing uncertainty, can be used to summarise what is known about a particular risk, these are not usually integrated with broadly-based deliberation or made user-friendly.

Characterising uncertainty in calculated risk assessments in a way that is both accurate and understandable may not be technically possible. A solution to dealing with uncertainty may lie in the process leading to a risk decision, whereby the participants are provided with enough understanding to appreciate where scientists and engineers agree and where they do not.

The risk characterisation process should be tailored to the needs of the decision which is to be made. Organisations responsible for characterising risk should anticipate the value-based judgements that are likely to become contentious and consider putting them on the agenda for the analytic/deliberative process.

Risk characterisation is more than a synthesis of information developed by analytical techniques. Analysis has inherent limitations in the face of the multi-dimensional and value-laden nature of many risk decisions. Analytical and deliberative processes should be blended in a way that clarifies the concerns of the interested and affected parties.

As part of an open, iterative and broadly-based deliberative process, uncertainty analysis should inform all the parties of what is known, what is not known, and the weight of evidence for what is only partially understood. Describing the uncertainty does not in and of itself represent or imply an advancement in that state; it does, however, help clarify what can be known and perhaps help identify directions for future research and data collection efforts.

If point estimates of risk are likely to contain significant errors, then explicit evaluation of uncertainty is needed. However, just as scientific judgements concerning point estimates are often tenuous and susceptible to overconfidence, so too are characterisations of the uncertainty in these estimates. Uncertainty analysis should avoid the temptation to view the evaluation and simulation results that some techniques of uncertainty analysis generate as the equivalent of field and laboratory studies and data. Also, formal uncertainty analysis may not help if the uncertainty in the fundamental understanding of the basic processes that drive the risk, or of whether the risk is even present at all, is so large that a quantitative estimate can only lead to obfuscation.

It follows that before an appropriate risk assessment methodology can be developed, it is necessary to define both the decisions which have to be made which could be assisted by risk assessment, and the appropriate level and nature of consultation. An understanding of the perceptions and needs of the stakeholders is also a prerequisite to a successful outcome.

4.2 Decisions

With respect to the types of decision within GEO's remit which could be facilitated by an assessment of the risks involved, it is perhaps appropriate to consider these at various levels, from the regional to the site specific. A classification of the various types of decision could be as follows:

(a) Regional scale: What resources should be made available to reduce deaths, injuries and economic loss from landslides, excavation collapses or excessive deformations, boulder falls and foundation problems?

    This is not a simple or easily-managed decision. In reality, GEO bids for resources for individual themes or projects, based on its own in-house estimates of where resources should be concentrated. Within GEO, the potential exists to create a process whereby the risks from these various hazards are discussed, and this could be a valuable management tool when it comes to prioritising bids for resources. Any comprehensive discussion of these risks would have to consider both the available numerical data (taking account of risk clustering and uncertainties as discussed earlier) and social factors, ideally within an iterative and consultative framework. Some work has been done already on the calculation of global risks from different types of landslide hazard, but further consideration is needed on how best to present and interpret these data. The only risk indicators which have been considered to date relate to the number of anticipated fatalities. This may not be adequate to reach an informed decision with respect to allocation of, or bids for, resources.

(b) Regional scale: How can GEO best measure the effectiveness of its policies and procedures?

    This is an area which has received much attention in recent years. Global risks from the failure of various categories of man-made slopes have been calculated and a trend of decreasing risk-to-life has been demonstrated. The risk indicator used has invariably been annual fatality rate within the population as a whole, which could be appropriate if the data are restricted in use to the evaluation of trends with time. However, it might be appropriate to consider whether the multi-dimensional nature of landslide risk should be accounted for when carrying out these types of assessment, i.e. should economic factors and/or social perceptions be integrated into the assessments of annual risk? In addition, care must be taken if using these data to either draw conclusions about acceptability, or to compare with other types of risk. As discussed earlier, the nature of the risk itself and the way in which it may be clustered can cause misleading conclusions to be drawn.

(c) Area scale: How should resources be allocated within the Landslip Preventive Measures programme?

The GEO uses the New Priority Classification System, or NPCS (Wong, 1998) as a first step for prioritising follow-up Landslip Preventive Measures action on features in the New Slope Catalogue. The NPCS is applied primarily to pre-GCO man-made slopes and retaining walls. Separate classification systems were developed for soil cut slopes, rock cut slopes, fill slopes and retaining walls. Under each system a Total Score is calculated for each feature, reflecting the relative risk of a failure. The Total Score is the product of an Instability Score and a Consequence Score. The Instability Score is calculated from a number of key parameters that affect the likelihood of failure. The Consequence Score reflects the likely consequence of failure. The higher the Total Score, the higher is the priority for follow-up action.

The Consequence Score reflects only the potential for loss of life in the event of a failure. It does not consider other possible dimensions of risk, such as transport inconvenience and economic loss (identified by HKU as additional social concerns relating to landsliding). There is potential here for further development.

The NPCS system provides an excellent example of how relative risk can be assessed in a formal manner by using a specific method designed to address a specific problem (i.e. which slopes deserve priority?). If multi-dimensional risk could be incorporated into such a system in a way which reflects societal concerns as well as assessed risk-to-life, the methodology could be very powerful, and could possibly be applied to other types of landslide hazard ranking.

(d) Site-specific scale: Is the risk to existing development from a given slope (or area of natural terrain) acceptable? If not, what should be done?

Some attempts to carry out this type of analysis in Hong Kong have met problems. Firstly, the inherent uncertainties must be considered when comparing results with "acceptance criteria"; secondly, application of "acceptance criteria" is not straightforward (for instance, if F-N curves are used, what proportion of the F-N curve should be below the "acceptable" line?); and finally, should societal perceptions also be addressed? If intending to carry our cost-benefit analysis to see what, if anything, should be done to mitigate risk, the same problems apply.

The great uncertainties in calculated risk (and the single-parameter nature of the risk indicator) cast doubt on whether design decisions should be made solely on this basis.

It could also be argued that a more productive way of looking at risk to existing developments would be a development of the NPCS approach in which various categories of slope (and possibly natural terrain) are prioritised for investigation using a multi-dimensional risk index.

(e) Site-specific scale: Is the risk associated with a proposed new development potentially affected by a man-made slope or area of natural terrain acceptable? If not, what should be done?

This is a variant of (d) above. In the case of an isolated development potentially affected by a slope or area of natural terrain it is possible to carry out an analytical risk assessment and compare this with "acceptance" criteria. The same problems of uncertainty and concentration on a single risk indicator apply, but the process can have value, particularly for those sites where calculated risks are significantly above or below "acceptance" thresholds. However, whether decisions as to absolute acceptability can be made on this basis is somewhat debatable, particularly in marginal situations or where there is high uncertainty (and this will, in fact, cover most cases). Where a development is proposed in an area in which there are already existing developments (or other proposed developments) a further difficulty arises: does one assess just the risk in the one development, or the cumulative risk in a given area? This question was also raised by the HSE in the UK, with no conclusions being reached. These various problems lead to the conclusion that the quantitative part of a risk assessment of this nature should form part of an integrated discussion of the risks associated with different types of site layout or mitigation. If used in this way, analytical methods could be useful in showing how the relative level of risk rises or falls as different design approaches are considered. Approaches such as this could supplement the conventional engineering approach of providing an adequate factor of safety against slope instability, which has its own limitations.

4.3 Consultation

The discussion in Section 4.2 above refers often to an iterative and consultative process in which the information available on risk is assessed by the parties concerned with, or affected by, the decision. Determining who should be involved in a given decision is not straightforward, particularly when, as is the case for GEO, there are existing statutory and administrative procedures which must be followed. However, if consideration is to be given to a review of who should be involved in various decisions, Stern & Fineberg (1996) offer the following list of questions, the answers to which can assist in identifying the interested and affected parties:

Who has information and expertise that might be helpful?
Who has been involved in similar risk situations before?
Who has wanted to be involved in similar decisions before?
Who may be affected by the risk characterisation?
Who may be affected but not know they are affected?
Who may be reasonably angered if they are not included?

5. CONCLUSIONS

Risk assessment should be an iterative and consultative process. Risk calculation can form part of this process, but it is not necessarily the most important part. Attempts should be made to integrate social perceptions with calculation in the risk assessment process.

Calculation of risk is subject to many uncertainties and these must always be recognised and addressed, using sensitivity analyses where appropriate. Decisions should not be made solely on the basis of calculated risk or cost/benefit analyses.

Risk is multi-dimensional. Limiting a risk assessment to one indicator (probability of death) may not always be appropriate.

Social perceptions of risk do not necessarily agree with objectively assessed risk. In Hong Kong, social perception of risk appears to be governed by a reasonably well-informed opinion of the probability of an individual's exposure to that risk.

When calculating risk, the risk indicator(s) chosen, and the way in which it is calculated, should be determined by the nature of the decision which is to be made.

With respect to landslide risk, different types of risk assessment and/or calculation will be required for different types of hazard and for different types of decision.

Calculated risk which relies heavily on statistical uncertainty analysis cannot be a substitute for data on, and understanding of, the occurrence, nature and behaviour of landslide and boulder fall hazards.

When comparing calculated landslide risk with risk from other hazards, the nature of the hazards and the population exposed to them must be considered.

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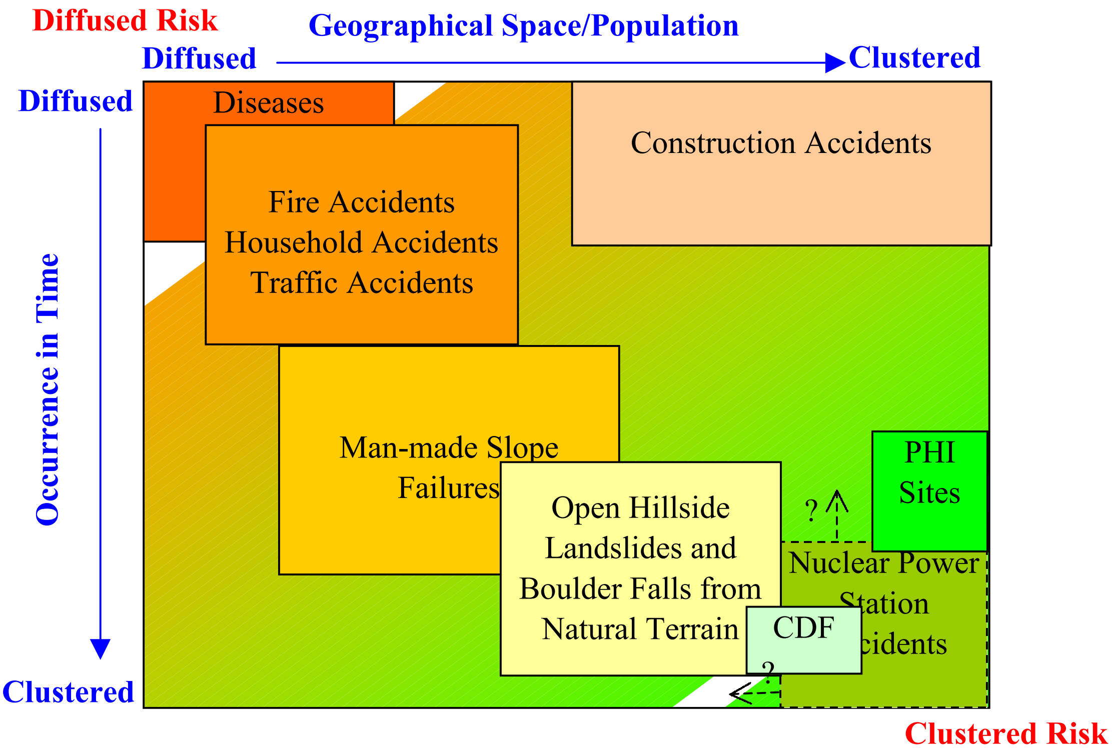
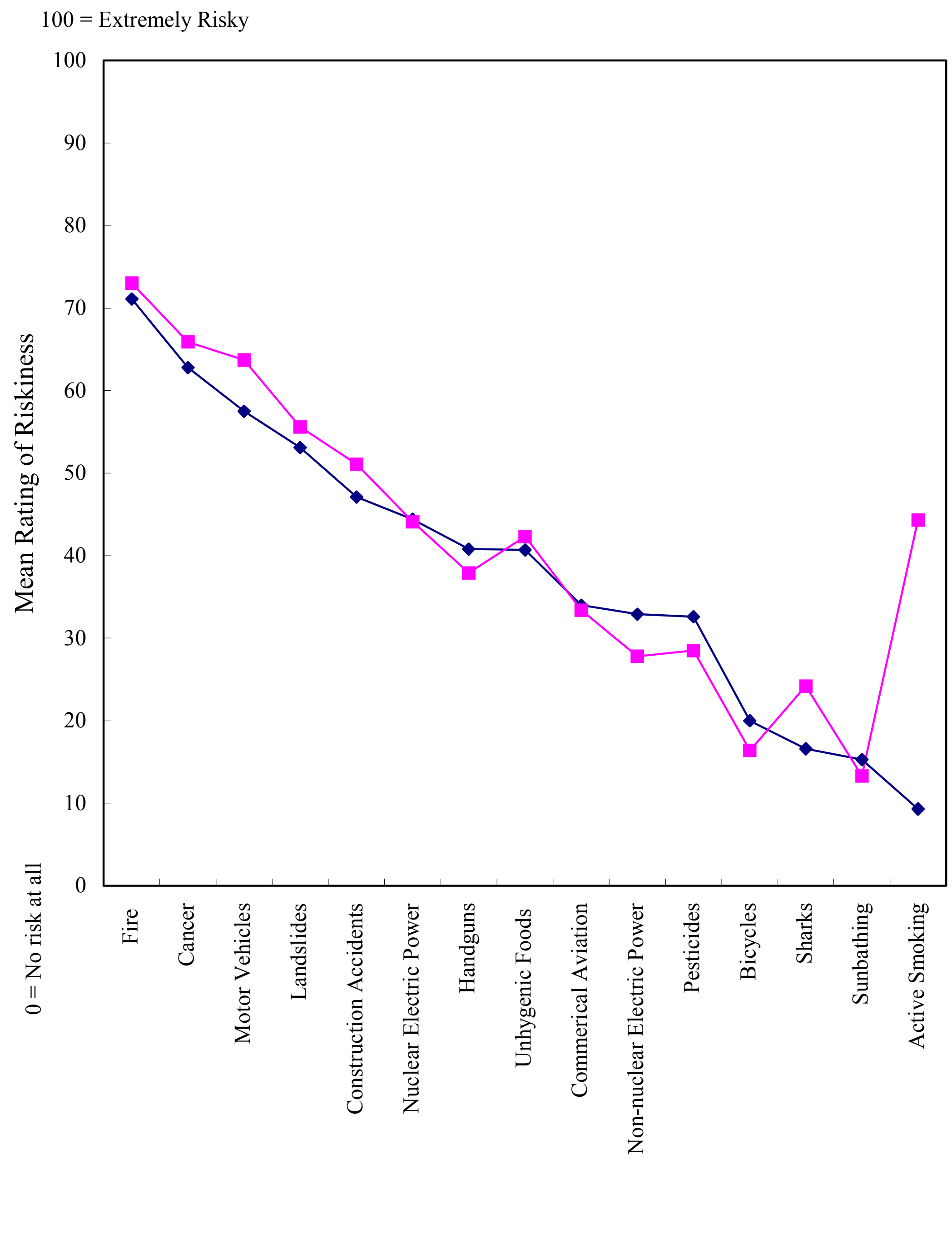
LIST OF FIGURES



Legend:

PHI	Potential hazardous installation
CDF	Channelised debris flows

Figure 1 - Subjective Assessment of Risk Clustering

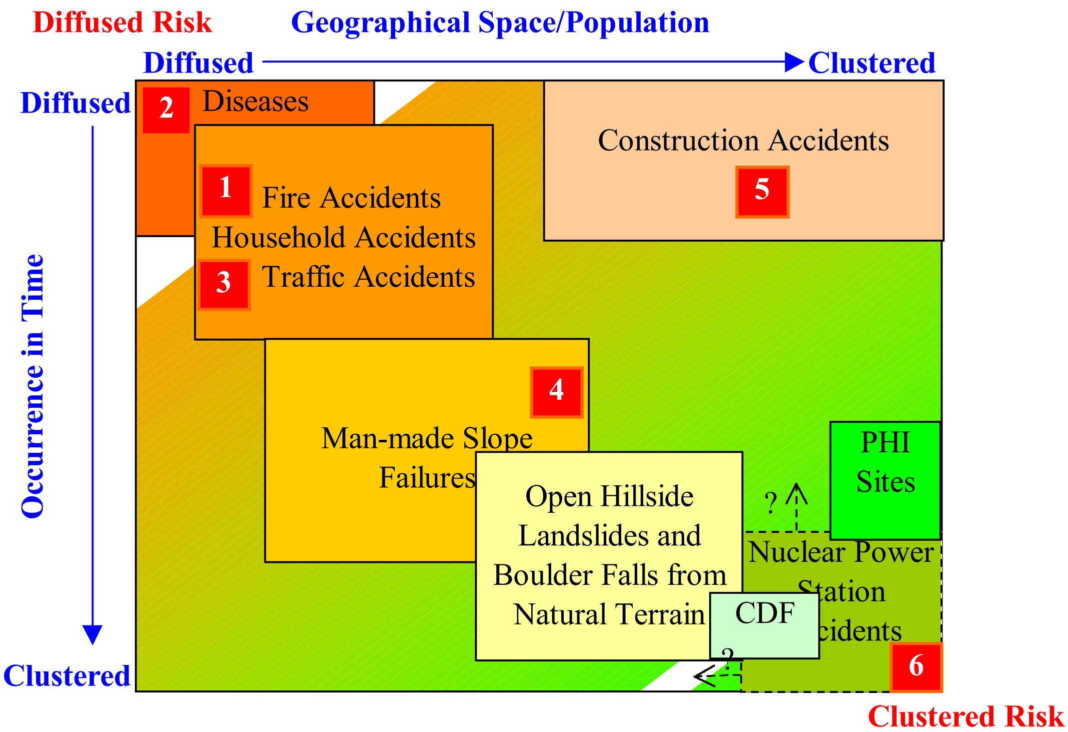


Legend:

Mean riskiness to me
Mean riskiness to a random person in HK

Note: Taken from HKU (1998).

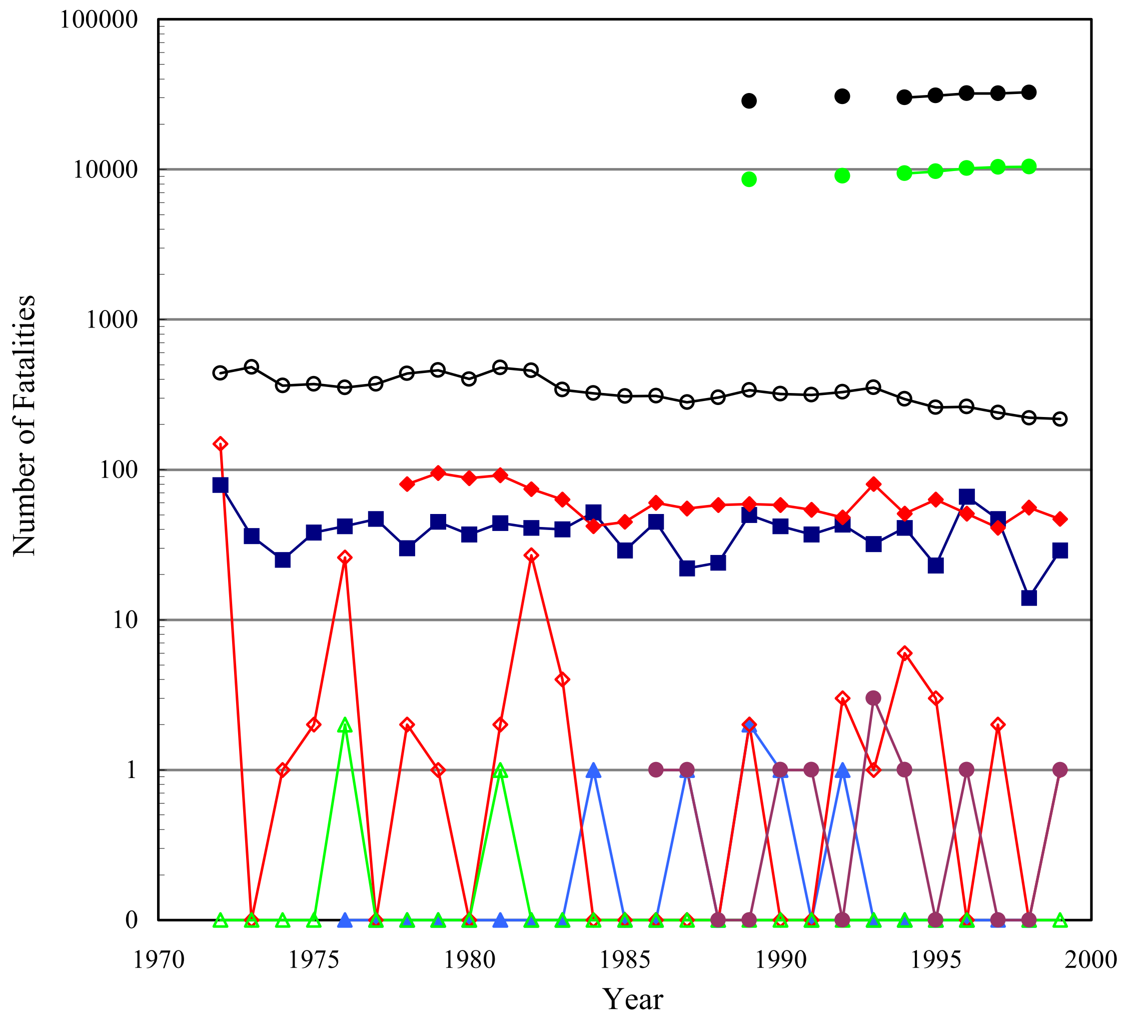
Figure 2 - Perceived Risk in Hong Kong



Legend:

PHI Potential hazardous installation
CDF Channelised debris flows
4 Ranking in perceived riskiness (after HKU, 1998)

Figure 3 - Public Perception of Risk Related to Risk Clustering

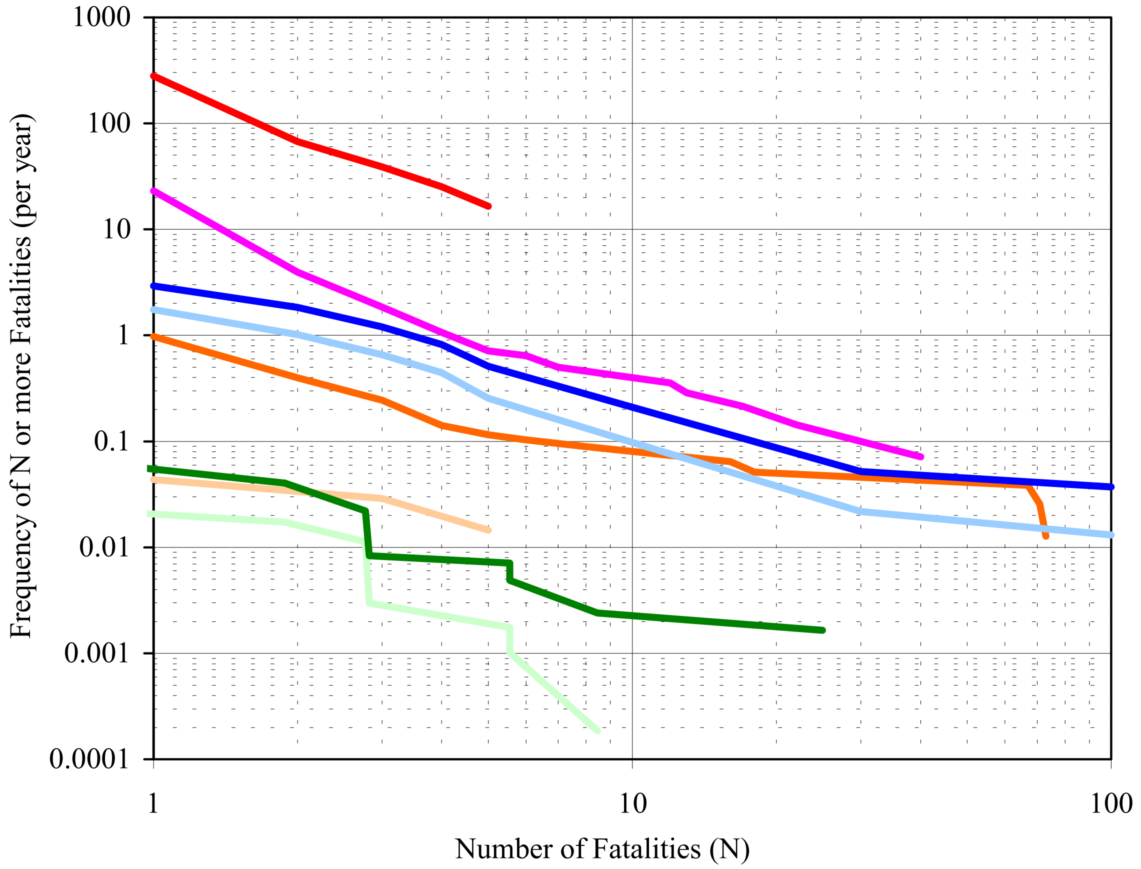


Legend:

- Total number of deaths[(1)]
- Road traffic accidents[(2)]
- Construction site accidents[(1)]
- Landslides (other than boulder falls)
- Trench collapse[(5)]
- Cancer[(1)]
- Fire[(3)]
- Lightning[(4)]
- Boulder falls

Notes:
(1) Figures are obtained from Hong Kong Annual Digest of Statistics - 1999 Edition on the internet web site of the Census and Statistics Department.
(2) Figures are obtained from Road Traffic Accident Statistics (1983-1999) by Transport Department.
(3) Figures are obtained from Fire Services Department direct.
(4) Figures are obtained from Census and Statistics Department direct.
(5) Figures are obtained from Kwong (2000).

Figure 4 - Statistics on Fatalities in Hong Kong (1972-1999)

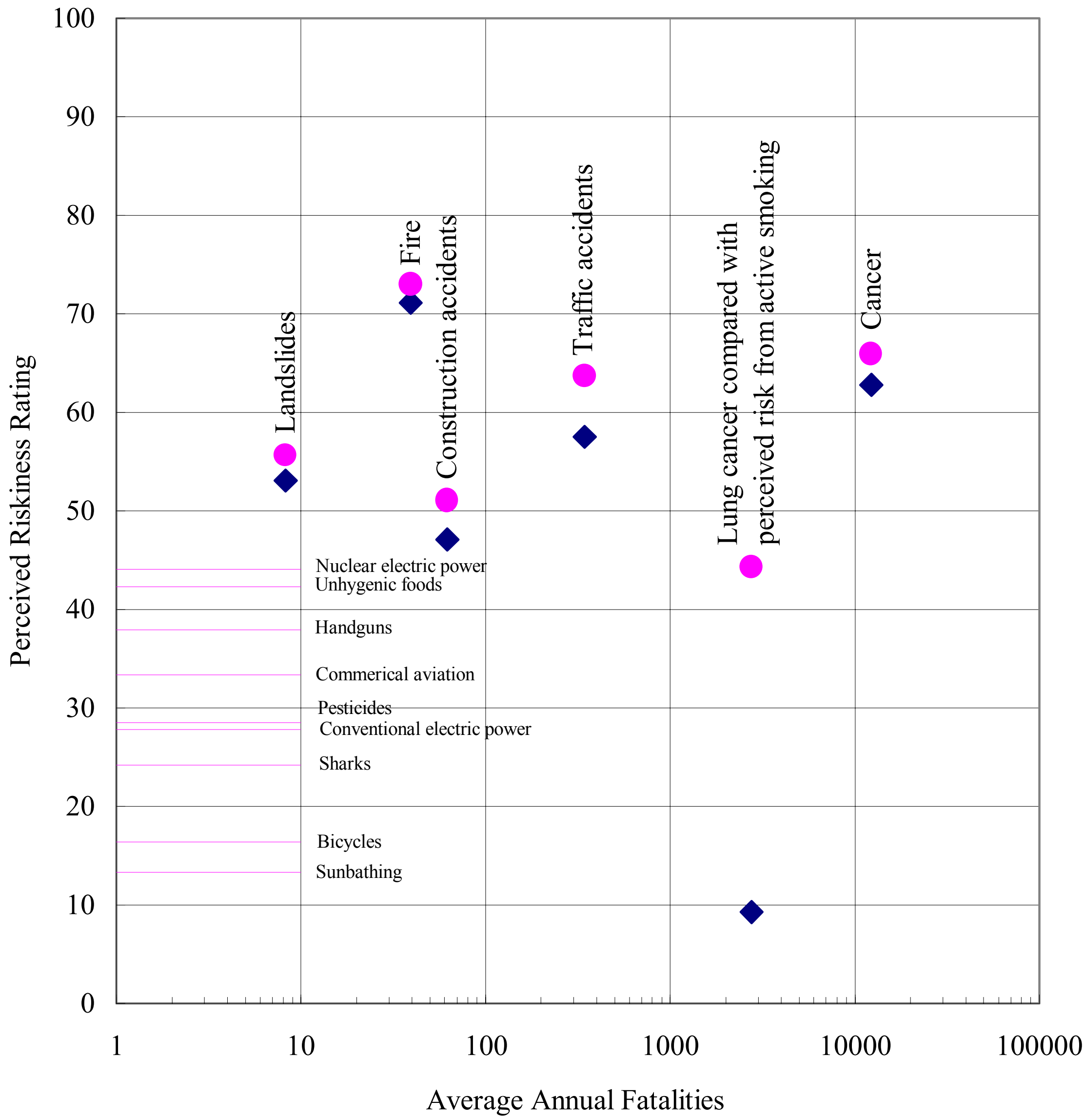


Legend:

- Statistics - Traffic accidents 1983-1999[1]
- Statistics - Fire accidents 1986-1999[1]
- Statistics - Historical landslide incidents 1917-1995[2]
- Statistics - Histrorical boulder falls 1926-1995[2]
- Analytical - Failures of pre-GCO man-made slopes in 1977[3]
- Analytical - Failures of pre-GCO man-made slopes in 2000[3]
- Analytical - Natural terrain landslides 1994 (base line case)[4]
- Analytical - Natural terrain landslides 1994 (base line + 20 m case)[4]

Notes:
(1) Sources of data are same as those in Figure 4.
(2) Data are extracted from ERM (1998).
(3) Data are extracted from Cheung & Shiu (2000).
(4) Data are extracted from Sun & Evans (1999).
(5) The analytical F-N curves presented above were derived to study relative changes in risk with time, and do not necessarily reflect actual fatalities.

Figure 5 - Multiple Fatality Events in Hong Kong



Legend:

◆ To me

● To a random person in HK

Notes:
(1) Sources of fatalily data are same as those in Figure 4.
(2) Ranges of annual fatalily data for caculations of average annual fatalities are same as those shown in Figure 4.
(3) Perceived riskiness ratings are obtained from HKU (1998).

Figure 6 - Annual Fatalities and Perceived Riskiness