

Risk Management and Slope Safety in Hong Kong

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Hong Kong's landslip problem is described in the context of post-war urban development and the progressive introduction of a safety regime since the 1970s. The safety regime acts both to reduce landslip risk and to address public attitudes to landslip risk. The components of the safety regime are explained and its impact is assessed. Evidence is presented showing prima facie that landslip risk has been significantly reduced by the safety regime in a cost-effective manner. The safety regime is analysed using the risk management approach, which provides pointers for its further development. The need is indicated for measurement of the efficiency and effectiveness of the individual component actions of the safety regime through quantified risk analysis and cost/benefit analysis. Preliminary work has been carried out on the use of quantified risk analysis in this application and the results are promising.

Keywords: Landslips, Safety Policy, Hong Kong, Quantified Risk Analysis, Risk Management

HONG KONG'S LANDSLIP PROBLEM

Hong Kong has become very safety conscious in recent decades and slope safety is regarded as a serious problem. The scale of the problem is indicated by the fact that landslips have been responsible for the death of more than 470 people in Hong Kong since 1948 (Figure 1). The landslip problem is essentially the product of post-war urban growth, for most of these deaths resulted from the collapse of man-made slopes, i.e. cut slopes, fill slopes and retaining walls created by the process of hillside development since the 1940s.

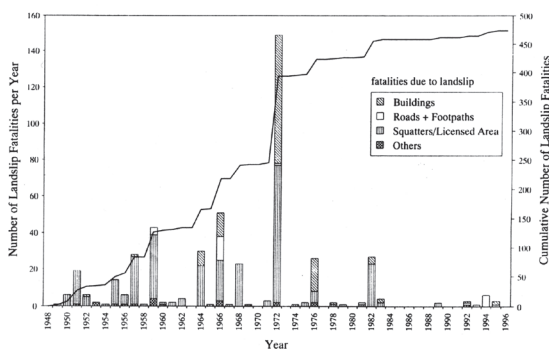


Figure 1. Landslip fatalities per year

Development pressures resulting from constant population growth in the past 50 years (Figure 2) in a limited land area have led to the intensive urbanization of the lower portions of the hillslopes in many parts of the territory. The state of hillside development in the early 1970s in public and private housing districts is shown in Figures 3 and 4 respectively. The hillsides have been terraced for roads and buildings and the

streams culverted, often beneath deep valley filling; much at the marginal land has been occupied by squatter villages.

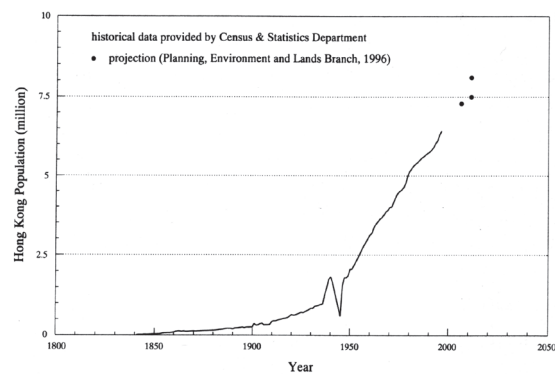


Figure 2. Population growth

There is evidence from analysis of fatal landslips suggesting that a significant portion of Hong Kong's landslip risk originated in the inadequacies of hillside development works in the post-war decades, along with lack of subsequent maintenance of constructed slope works (Hong Kong Government, 1972b and 1977; Geotechnical Engineering Office, 1993a, 1993b, 1994, 1996a and 1996b; Chan et al, 1996). The landslip problem appears to have intensified in the late 1960s, judging from fatality rates per million of population increase (Figure 10).

Nearly all of Hong Kong's landslips are rain-induced. During the summer months the territory experiences intense rainstorms, either when troughs of low pressure settle near the South China coast, or during the close passage of tropical cyclones. The hillside streams draining the small steep

catchment grounds then quickly become swollen with stormwater, and hillside roads often become watercourses themselves. Whilst the storm lasts, which may be hours or even days, affected slopes that are not well built or well maintained become prone to water-induced landslip, either through surface erosion or internal de-stabilization. Hundreds of landslips may be reported from the more severe rainstorms and landslips occurring in a few such events dominate the annual statistics. Since central recording began in 1984, between about 80 and 800 landslip incidents have been reported to the Geotechnical Engineering Office (GEO) each year. In some years the greater proportion of reported incidents occurred on only one or two days.

Three other features characterize reported landslips in Hong Kong: most are very small, movements are brittle, not ductile, and nearly all are associated with man-made slopes. Many unreported landslips are known to occur on undeveloped natural terrain subjected to intense rain, being visible in aerial photographs, but these go unrecorded, having little impact on the community. Nearly all reported landslips in Hong Kong occur suddenly during rainstorms and move rapidly. Since 1984, about half of the reported landslips were less than 5 m³ in volume and only around 10% were of greater volume than 50 m³. But experience has shown that even small failures create severe hazard in certain circumstances e.g. in close proximity to squatter dwellings. Since 1971, more than half of the fatal landslips in squatter areas have been less than 50 m³ in volume. In contrast, nearly all of the landslips in this period causing the death of pedestrians, motorists and people in multi-storey buildings have been of much greater volume. The greatest recorded harm has been caused by collapses of earthworks developing into large rapid mobile flows, which have proved capable of demolishing multi-storey buildings with the loss of scores of lives.

CREATION OF A POLICING BODY

Two disastrous rainstorms occurred in 1972 and 1976, coinciding with a period of administrative reform in Hong Kong, and a central slope policing body was created in 1977.

The two most destructive landslips in the recent history of Hong Kong took place on 18 June 1972, the third day of a severe rainstorm associated with a trough of low pressure. Shortly after 1 pm, a major landslip occurred in the Sau Mau Ping Resettlement Estate in the Kowloon foothills. The failure, illustrated in Figure 3, involved the collapse of the side-slope of a 40 m-high road embankment constructed on sloping ground. The resulting flowslide destroyed many huts in a licensed temporary housing area, killing 71 people and injuring 60 others (Hong Kong Government, 1972a). Hours later, another major landslip occurred, in a private residential district on a steep hillside at

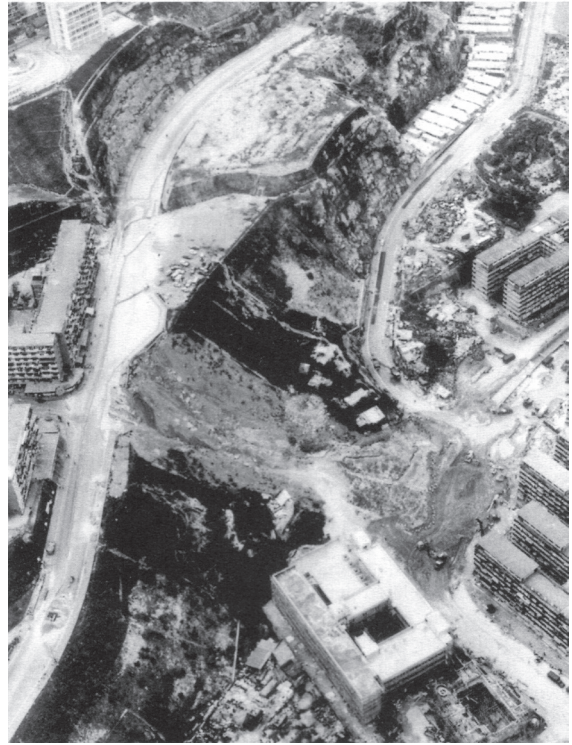


Figure 3

Po Shan Road in the Mid-levels area of Hong Kong Island. Sixty-seven people were killed and 20 injured when an occupied 12-storey private apartment building was demolished under the impact of an extremely rapid flowslide (Hong Kong Government, 1972b). The landslip, illustrated in Figure 4, was initiated on the hillside above by the collapse of a steep cutting in a works site for a private building.



Figure 4

A commission of enquiry, set up amidst the ensuing public outcry, reported in August and November (Hong Kong Government, 1972a & b) and by the end of the year a group of civil engineers had been assigned to the building control office to vet the geotechnical

aspects of private development submissions.

Four years later another destructive landslide occurred in the Sau Mau Ping Resettlement Estate, on the morning of 25 August 1976, following heavy rainfall associated with a Severe Tropical Storm. At least four landslides took place in the estate resulting from the collapse of the side-slopes of highway embankments formed of earth fill. Three of these turned into flowslides, the most hazardous occurring on the face of a 35m-high embankment above an occupied public housing block. The debris moved downwards as 'a large sheet' until arrested by the building, the ground floor rooms of which were inundated by fluid mud, trapping many occupants; eighteen people were killed and 24 seriously injured. Subsequent investigation found that the collapse had occurred because the earth fill forming the face of the slope was in a loose condition, having been placed by end-tipping without compaction, contrary to good practice (Hong Kong Government, 1977). The 1976 Sau Mau Ping landslide brought the number of landslide fatalities in a four-year period to greater than 175 (Figure 1). Immediately after the landslide the Governor established an Independent Review Panel on Fill Slopes, comprised largely of overseas geotechnical experts, which recommended the creation of a central policing body to regulate the whole process of investigation, design, construction, monitoring and maintenance of slopes in Hong Kong (Hong Kong Government, 1977).

The geotechnical control body, created in July 1977, has since evolved in response to experience and through reform initiatives (Malone & Ho, 1994) and today, Hong Kong has a well-developed slope safety regime. The GEO manages the safety regime, which will be referred to as the 'Slope Safety System', and undertakes policing, research and educational functions; it also carries out specialist works projects. The component actions of the Slope Safety System are given in Table 1. The aims are twofold: to reduce risk and to address public attitudes to risk. Along with GEO as safety manager, the main action parties in respect of slope safety are the private owners and government agencies that are responsible for the safe construction

of slopes and the maintenance of their stability. Several other parties are involved in slope safety, including the risk bearers, the resource allocators and the media, as indicated in Figure 5.

RISK MANAGEMENT

A process for handling risk to satisfy the needs of the parties involved, referred to as 'risk management', has become well-established in the hazardous industries (Royal Society, 1992) and has been adopted in Hong Kong by the Government for the management of risk in the vicinity of installations storing large quantities of certain hazardous chemical materials (Hong Kong Planning Standards and Guidelines, 1996). Hong Kong's landslide problem may be analysed using the risk management approach and such an analysis may provide useful insights and pointers for the further development of the Slope Safety System.

Adopting a risk management approach requires the calculation of risk, the making of a decision on whether this level of risk is tolerable (by reference to guidelines for tolerable risk levels i.e. 'risk criteria') and, if it is not, the taking of action to control, prevent or reduce it, weighing cost, including non-financial costs, and benefit. Risk, 'chance of defined harm', is a probability and Quantified Risk Analysis (QRA) provides the methodology to calculate this quantity. One of the risks to be calculated for the purpose of applying the risk management approach to the landslide problem is the risk to Hong Kong as a whole from landslides ('global risk'), expressed in terms of the annual probabilities of certain amounts of harm to people, such as fatalities, serious injuries, evacuation of people from buildings; and of other detriments, such as road traffic disruption and the cost of landslide repairs.

The risk management tool appears to have potential in slope safety management in Hong Kong for, once risk can be quantified, the effectiveness of the safety system can in principle be gauged in terms of outcome i.e. reduction in global landslide risk. Further, through the quantification of risk the safety system manager has the means to take management decisions on a rational, consistent and defensible basis.

In considering further the application of the risk management process, three important questions arise: 'can landslide risk be reliably estimated?', 'can landslide risk criteria be established?' and 'can landslide risk control, prevention and reduction options be evaluated in terms of cost and benefit?'

THE SLOPE SAFETY SYSTEM

These questions will be considered later in the paper but first the component actions of the existing Slope

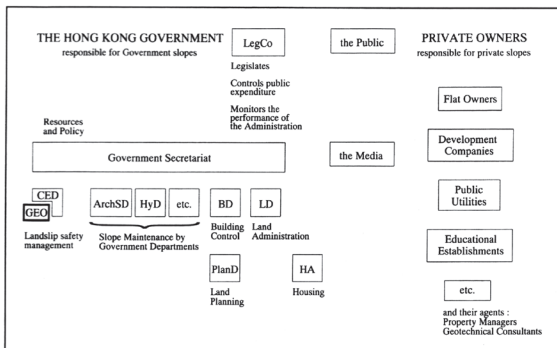


Figure 5

Safety System will be explained. The components of the system may be grouped, as shown in Table 1, into 'policing' actions, research and the setting of standards, specialist works projects and educational and information services. The contribution which each of these component actions makes towards the two aims of the Slope Safety System (reducing risk and addressing public attitudes to risk) is indicated in the table.

Table 1. The Slope Safety System

Slope Safety System components	contribution by each component		
	to reduce landslip risk		to address public attitudes
	hazard	vulnerability	
policing			
cataloguing, safety screening and statutory repair orders for slopes	✓		
checking new works	✓	✓	
maintenance audit	✓		
inspecting squatter areas and recommending safety clearance		✓	
input to land use planning	✓	✓	
safety standards and research	✓	✓	✓
specialist works projects			
upgrading old Government slopes	✓		
preventive works for old tunnels	✓		
education and information			
maintenance campaign	✓		✓
personal precautions campaign		✓	✓
awareness programme	✓	✓	✓
information services	✓	✓	✓
landslip warning and emergency services	✓	✓	✓

The system has evolved over a twenty-five year period. To recap, site formation and subsequent maintenance of slopes by private owners and Government departments went largely unregulated before the creation of the civil engineering unit in the building control office in 1972 and then the central policing body in 1977. By this date a very large amount of development, both legal and squatter development, had already taken place on hillslopes. Some of the developments constructed on hillslopes during the unregulated period turned out to contain design or construction defects, when judged on modern standards, causing failure with attendant harm and damage.

Therefore, when the policing body was established it was given two main duties; to establish a control regime for new works on hillslopes, to prevent any increase in risk due to defective new works by government departments or private developers, and to be the manager of the recently established slope retrofit programme, under which sub-standard works of the past would be brought up to modern standards by their private or government owners, with a corresponding reduction in risk. These duties remain the major elements of GEO's work in terms of resources

deployed. GEO took on new tasks in the 1980s with the introduction of squatter safety clearances and in the 1990s with its educational initiatives, initially targeted at slope owners to promote good maintenance practice.

Policing Actions

Risk may be reduced by policing actions aimed at reducing hazard, e.g. by lessening the frequency of occurrence of landslips. Hazard may be reduced by the owners' retrofit and maintenance programmes for existing slopes and through the GEO's checking regime for new work. *The GEO's policing responsibility in the retrofit programme* comprises the cataloguing (in 1977/78) and subsequent safety checking, in risk priority order, of existing man-made slopes formed before the GEO was established ('old' slopes) and initiating, by statutory or administrative action, the upgrading of slopes found to be sub-standard. Thus, between 1976 and March 1995, some 1000 old private and Government man-made slopes were upgraded by their owners out of an estimated number of more than 35,000 old man-made slopes of significant size.

The *checking regime* for new works involves the GEO in vetting designs against published technical standards, the requiring of qualified supervision of works and spot-checking on site that the required standard of site supervision is being met. Generally, private sector development is regulated under the Buildings Ordinance and Government work is controlled under an administrative mandate. Some 15,000 or more slopes have been constructed since GEO was established and, after construction, each needs to be maintained on a regular basis. The Lands Department is responsible for all aspects of land administration and it assigns Government slopes to departments for maintenance purposes (Figure 5). In the case of Government slopes, maintenance work is carried out generally by the works department responsible for their construction and, from 1997, GEO will *audit their compliance with the published slope maintenance standard*.

Landslip risk may also be reduced by policing actions aimed at reducing vulnerability, i.e. the exposure of people and property to hazard. In squatter areas, for example, it is policy to clear structures which are 'especially vulnerable' to landslip during rainstorms and to rehouse the occupants. 'Especially vulnerable' structures are identified by geotechnical engineers in a *systematic squatter area inspection programme*. Since the early 1980s, at GEO's behest, some 72 000 hut-dwellers have been cleared from hillsides by the Housing Department and rehoused under the 'non-development' clearance programme. Over this period there has been a corresponding decline in the proportion of reported landslips affecting squatters (Figure 6) and squatter fatalities due to landslip (Figure 1).

Geotechnical control input into land use planning is aimed at minimising landslip risk, and to this end geotechnical zoning maps and reports were published in the 1980s, providing geotechnical information in a usable format for the Planning Department's planners. However, the advance of development into areas classed as 'high geotechnical difficulty' has continued, with inevitable increase in landslip risk. This concern is being addressed in the natural terrain landslip risk management strategy referred to later. Two of GEO's other contributions to territorial development have, as an added benefit, enhanced slope safety, by helping to make some hillside development unnecessary through provision of alternative land. Thus, some 300 million m³ of marine-dredged sand have been supplied in the 1990s through the work of the Fill Management Division of GEO, to reclaim land from the sea for development (Ooms et al, 1993). The Office also facilitates the use of space created underground in man-made rock caverns - another means of avoiding undesirable hillside development (Hong Kong Planning Standards and Guidelines, 1996).

publications and professional guidance documents have been widely distributed; by December 1996 about 49,000 copies had been sold, 6-8% annually overseas.

Works Projects

Having established its policing functions by the early 1980s, GEO then took on various *slope-related specialist works projects* on behalf of the Government agencies responsible for maintaining the stability of slopes (Figure 5). These projects include the management of the Landslip Preventive Measures (LPM) programme, under which old slopes are upgraded to modern standards, and the project for the stabilization of disused wartime air raid tunnels. In the climate of heightened public awareness of landslip danger following the Kwun Lung Lau landslip in 1994, which caused five deaths and the evacuation of thousands of people, support was obtained in 1995 from the resource allocators (Figure 5) for a five-year project to increase the staffing and funding resources being applied to the LPM programme. The five-year project allows upgrading works on Government slopes and the service of statutory repair orders on private slopes to be undertaken at a greatly increased rate for a further five years, and as a result about 10% of the estimated number of old slopes will have been upgraded by the year 2000.

Education and Information

During the 1980s, GEO's *public educational and information services* largely catered for the needs of the geotechnical profession, but a major expansion of these services was initiated in 1992. This was in response to the realization that many private flat owners were unaware of their legal responsibility to maintain the stability of the land within and, in some cases, outside their lot boundary. Accordingly, a public education campaign was launched in 1992 to inform owners of their responsibilities and to encourage them to maintain their slopes properly. Television, radio and street advertising of various kinds are used to put across the slope maintenance message, along with community action in many forms. The effect of the campaign is monitored annually by means of public opinion surveys, which show high awareness of the message and confirm that the only advertising which achieves significant impact is television advertising (Social Science Research Centre, Hong Kong University, 1996 & 1997; Yim et al, 1997). Not only is there evidence of awareness of the message, there is also evidence of corresponding action. An annual survey of 60 to 100 sites is carried out to gauge the level of slope maintenance action by private owners and the results show a gradual increase in action since 1993 (Yim et al, 1997). However, in attempting to explain this trend it is not possible to separate out the influence of the GEO's slope maintenance campaign

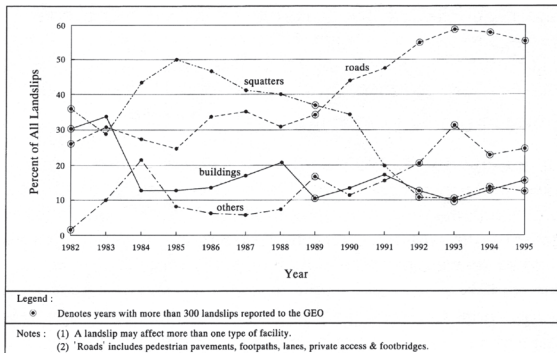


Figure 6. Facilities affected by landslips

Landslip risk from natural terrain unaffected by development appears to be low but not negligible. The 1150 m long Tsing Shan debris flow of 1990, which reached the western part of Tuen Mun new town, and the large numbers of natural terrain landslips in the Tung Chung area in 1992 and 1993, drew attention to the possibility of destructive landslips from natural slopes. The threat is likely to increase if more land on or adjacent to steep hillsides is released for housing to meet the projected population demand (Figure 2). Accordingly, a new natural terrain landslip risk management strategy is being developed, for execution through the town planning, development approval and works functions of the existing safety system.

Safety Standards and Research

In support of its policing, works and educational functions GEO undertakes *research and the setting of standards*. It also undertakes thorough forensic investigations of fatal landslips. Its research

and the positive influence of publicity surrounding the fatal landslips of recent years (see Figure 1).

With the aim of reducing the vulnerability of people to landslip hazard, a public education campaign was started in 1996 which informs the public about the personal precautionary actions to be taken to limit their exposure during the short periods each year when the Landslip Warning (described below) is in force. At the time of writing the campaign is still at a low level but, to increase impact, the screening of a new TV movie advertisement is planned for the 1997 wet season.

In response to demand, which intensified in 1992, GEO provides advice on slope safety and slope-specific information to slope owners and the general public. A telephone hotline service installed in 1992 gives advice to callers on slope safety matters and sends lists of registered geotechnical engineers, etc., by autofax and takes orders for layman's guides and other consumer items. Some two thousand callers were served in 1996. In line with the Government's general commitment to release as much information as possible, internet access will be provided to the slope-specific database by 1998.

GEO's *landslip warning and emergency services* were established in 1977. The Landslip Warning was introduced to encourage precautionary evacuation of vulnerable squatter settlements at critical times and is broadcast by means of regular announcements on radio and TV. The announcement was expanded in 1996 to cover pedestrians and motorists and at the same time landslip danger signs were posted at hundreds of sites throughout the territory. The Landslip Warning has been issued three to four times annually on average and remains in force for about a day but the GEO emergency service is on standby 24 hours per day year-round and, when activated, can become a major commitment, e.g. more than one hundred geotechnical staff were deployed to landslip sites on each occasion during rainstorms in 1992, 1994 and 1995 to advise the police, the fire department and slope owners and maintenance agencies.

Since 1995 GEO has given media skills training to more than 150 of its professional staff and operated its own media unit, capable of being upgraded into a communications centre during a crisis to meet the immediate surge in demand for information which a disaster creates. As a result of these initiatives the media are nowadays better informed about slope safety than they were in the past, according to the annual GEO media audits (Au-Yeung & Ho, 1997).

Maintaining Risk Awareness

There is a natural tendency for people to assume that hazards which are no longer prominent have been eradicated and for a false sense of security then to prevail. As a result, safety declines.

The link between public awareness of landslip danger and maintenance action by owners was pointed out in the 1970s, (Lumb, 1975). Further evidence of the

impact on slope safety of the fluctuations in the level of public awareness has emerged in the last 20 years. By 1991, following eight years without publicised landslip fatalities (Figure 1), public awareness had declined to a low level and the perception prevailed that the landslip problem had been solved. No estimate of remaining risk level was then available from QRA with which to counter the prevailing attitude. A false sense of security does not engender a high level of support, compliance or preventive action on the part of those involved in slope safety (Figure 5). Although public awareness rose dramatically in the years 1992 to 1995, and is still running at a high level, it is likely to decline again, after a series of uneventful years without publicity. If awareness is lost, risk may be expected to increase. Risk will increase without steady support by resource allocators for the slope safety effort, without compliance by private and government developers and owners with slope safety policing and without the requisite level of self-initiated preventive action by slope owners and precautionary action by the general public. Experience over thirty years in Hong Kong has shown that such support, compliance and preventive action are positively influenced by public awareness of landslip risk (Malone & Ho, 1995; Yim et al, 1997).

An awareness publicity programme is required to sustain public attention and concern. The public education campaigns on slope maintenance and personal precautions referred to earlier, with TV advertising as the core element, are the basis of the programme. The impact of the awareness programme is to be monitored by public opinion surveys and measurements of behaviour indicative of awareness. One such behavioural measurement for example is the proportion of private owners undertaking maintenance work on their slopes, the trend of which is revealed in the annual maintenance surveys of 60 to 100 sites referred to earlier.

Addressing Public Attitudes to Landslip Risk

It became apparent in the 1990s that the level of landslip risk tolerability in Hong Kong was much lower than in comparable places, such as Taiwan and Korea, and had become unrealistically low. Consideration was therefore given to investigation of public attitudes to landslip risk and to possible actions to address tolerability, including those indicated by the results of studies carried out into the perception and communication of risk by psychologists and sociologists, a recent summary of which is given in Royal Society (1992). Following on from the concepts presented in Royal Society (1992), Pigeon (1995) gives evidence which suggests that trust, credibility and risk tolerance in respect of plant safety may be fairly simply related to efforts to develop (or not) safe plant institutional designs; and secondly, that good plant risk management on the one hand and local community trust on the other might have a mutually reinforcing

relationship. These insights were developed into a tolerability rationale which GEO has been applying on a pilot basis since 1995.

The tolerability rationale is, that increasing risk tolerance will rely on convincing key parties involved in the Slope Safety System (Figure 5), hereafter referred to as 'stakeholders', that best efforts in all respects (e.g. accountability, expertise, effectiveness and efficiency) are being employed by GEO to reduce landslide risk. Guided by the tolerability rationale, considerable efforts are being put into improving dialogue with and responsiveness to stakeholders through the various communication channels and accountability mechanisms referred to in the appendix. The first aim was to win the trust of the media, without which effective communication to many of the stakeholders is impossible. Along with a sustained year-round media and public relations effort, the critical need was recognized for effective communication and response at times of landslide emergency, and accordingly provision for a crisis communications centre was made in 1995. These measures seem to be working, for there is evidence that some success has been achieved with the media since 1994 (Au-Yeung and Ho, 1997). In preparation for the next phase of the programme, baseline surveys of risk perception (Keown, 1989) are being conducted with stakeholder groups and a new TV-based educational campaign is being designed to better explain the nature of landslide risk. Objective measures of risk perception and risk tolerance are being devised so that future trends in public attitudes may be monitored, by which to judge the effectiveness of GEO actions to address tolerability.

EVALUATION OF THE SLOPE SAFETY SYSTEM

Having described the component actions of the system in the previous section it is now appropriate to examine evidence of its effectiveness and efficiency with respect to the first aim: to reduce risk. Evaluation of actions to address public attitudes is premature since the tolerability programme only commenced in 1995.

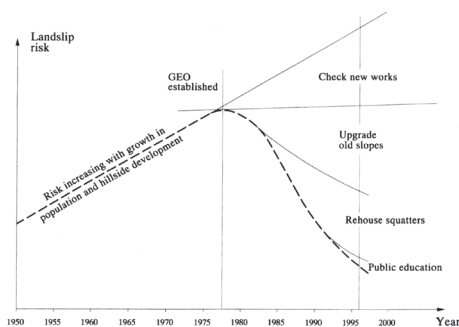


Figure 7. Postulated risk trend

If landslide risk has been reduced by the Slope Safety System, the trend depicted in Figure 7 ought to be apparent. This hypothetical global risk trend is based on the premise that risk increased with population growth (Figure 2) until arrested and then reduced by the intervention of the Slope Safety System. It is postulated that, without the Slope Safety System, landslide risk would have continued to increase with continuing growth in population, the encroachment of development onto steeper terrain, the increase in the number of man-made features and their deterioration due to lack of maintenance.

However, risk has to be calculated by QRA and to measure change in risk with time, QRAs must be carried out for different times. As this work has not yet been done, evaluation of the outcome of the Slope Safety System will have to rely for the present on indication of risk rather than calculation of risk by QRA.

A reducing trend with time in the amount of harm and damage occurring annually due to landslides, when normalized for rainfall, would be a prima facie indication of a reduction in risk. Trends in data can be revealed by plotting rolling averages (i.e. moving averages) and this technique is adopted here, using a 15-year averaging period. For want of other reliable historical data, in this exercise harm is expressed solely in terms of landslide fatalities. The plots in Figures 8 and 9 utilize landslide fatality data for the whole territory for 49 years and rainfall data from the Royal Observatory gauge at Tsim Sha Tsui for a corresponding period. The prior 15-year rolling averages of annual number of landslide fatalities are given in Figure 8; other averaging periods show a similar pattern. In an attempt to discern trends in rainfall, the corresponding 15-year rolling averages of the annual number of heavy rainfall events, defined as an event giving 24-hour rainfall greater than 175 mm, and the annual rainfall are also plotted (Figure 9). The former criterion is chosen because the expectation of 175 mm of rain in 24 hours at Tsim Sha Tsui is the main Landslip Warning criterion. The trends for various other 24-hour rainfall amounts greater than

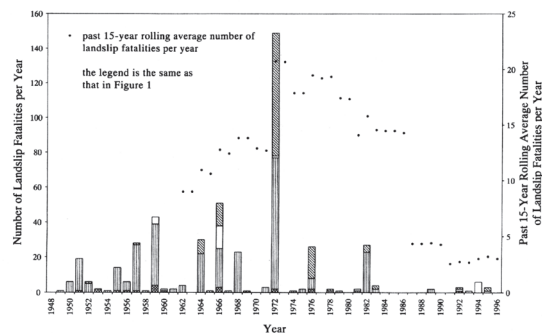


Figure 8. Landslip fatalities per year

125 mm are broadly similar to those for 175 mm.

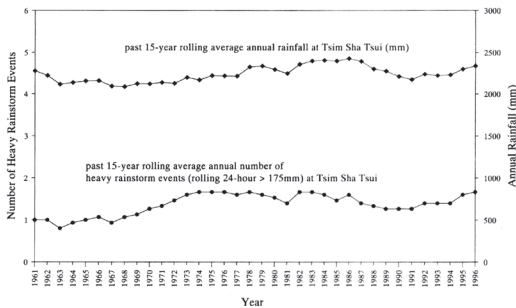


Figure 9. Rainfall trends

The rise and fall trend in annual fatalities illustrated in Figure 8 resembles that of the hypothetical risk trend in Figure 7 but Figure 9 shows no commensurate reduction in annual rainfall or the number of heavy rainfall events in the last 20 years. This finding may be interpreted as indicating a reduction in risk in the last 20 years. Another indication of reduction in risk would be any reducing trend in territorial landslip fatality rate with increasing territorial population, when normalized for rainfall. These data for a 49-year period are plotted in Figure 10, and a significant reduction in fatality rate with population growth is evident, beginning in the 1970s. The trends depicted in Figures 8 and 10 provide prima facie evidence of significant landslip risk reduction since the 1970s, i.e. since the introduction of the slope safety regime. The rate of landslip fatality per year per person (past 15-year average) is now about 5×10^{-7} , which is ten times lower than it was in 1976.

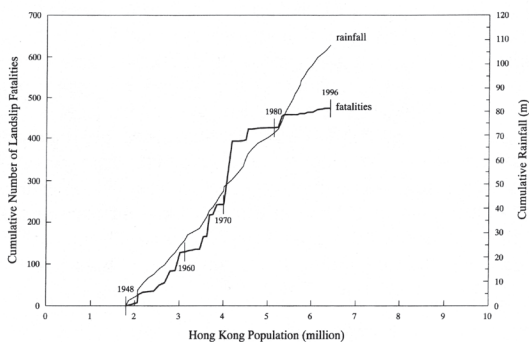


Figure 10. Landslip fatalities and population growth

A number of possible defects in the above rationale must be addressed. First, the rainfall normalizers used may not be the best nor even appropriate, leaving open the faint possibility that the reduced fatality rates of the last 20 years are due to abatement of rainfall rather than the Slope Safety System. Second, it may

be argued (referring to Figure 7 'rehouse squatters') that some non-development clearance of squatters in Hong Kong and Kowloon would have happened with or without the GEO inputs. Third, it may be claimed (referring to Figure 7 'check new works') that the apparent safety improvement has resulted from a general upgrading of quality in the construction industry over the same period, rather than the Slope Safety System. There are arguments to counter all three contentions, but the matter will not be elaborated here. Rather, the findings of significant risk reduction will be referred to as 'prima facie' at this stage.

In evaluating the efficiency of the Slope Safety System as a whole in terms of outcome, the fundamental question is 'is Hong Kong getting value for money in terms of cost/benefit?'. Preparatory work for application of cost/benefit analysis to GEO's slope safety work is now progressing under the R&D programme but no results are available; a crude calculation must therefore suffice in answer for the present.

Projecting forward the fatality rate trend prior to the 1980s shown in Figure 8, it appears that an annual fatality rate (past 15-year rolling average) of the order of thirty-five fatalities per year might have been reached by 1996. In fact the actual annual fatality rate in 1996 (past 15-year rolling average) was of the order of three fatalities per year. Taking these figures at face value, attributing the reduction to the Slope Safety System, making assumptions about the 19-year direct cost of the Slope Safety System and charging its entire cost to saving life only, it is estimated that up to the end of 1996 each life saved has cost about \$20 million. The figures for 10-year and 20-year averaging periods are \$18 and \$25 million respectively. These figures would probably be regarded as cost-effective by those of the main stakeholders (Figure 5) prepared to consider the matter in these terms.

The figures of \$18 to 25 million are towards the lower end of the range of values of statistical life assumed in risk assessments for technological hazards in Hong Kong current practice. Therefore, purely according to the cost/benefit rationale which is often used in risk management practice, given that risk exceeds a tolerable level, the need is indicated for continuing investment in landslip risk reduction in Hong Kong.

POTENTIAL FOR APPLICATION OF QRA AND RISK MANAGEMENT

Various pilot applications of QRA and the risk management process, summarised in this section, have indicated that the tools have potential in slope safety management in Hong Kong.

In identifying squatter structures which are 'especially vulnerable' to landslip during rainstorms the inspecting geotechnical engineer employs a visual

inspection method statement. The results of the use of the method statement have recently been tested by risk assessment. The method statement approach was routinely applied in the Lei Yue Mun squatter areas in 1995 and a clearance zone thereby delineated. Later, a risk assessment using QRA was undertaken to identify areas with unacceptable risk (Smallwood et al, 1997) and reasonably good correspondence was found between the zone thus defined and that given by the method statement.

The policies employed to apportion retrofit funding and for the prioritization of old slopes for stability study have recently been tested using preliminary QRAs. Global risk from old man-made slopes has been conservatively estimated from preliminary QRA calculations at about eleven fatalities per year (Potential Loss of Life) (Wong et al, 1997). This compares with a PLL value of 0.1 fatality per year for risk from boulder-fall from natural terrain (Chan et al, 1997). Therefore the high priority given in the Slope Safety System to the upgrading programme for old slopes, as compared to the mitigation of boulder-fall hazard, is commensurate with the relative risk indicated by preliminary QRAs. The QRAs also show the effectiveness of the risk prioritization of old slopes for stability study. As stated earlier, only 10% of the number of old man-made slopes will have been upgraded by the year 2000 but global QRA calculations suggests that this may represent some 50% of the total risk due to old man-made slopes in 1977. The research has also revealed unexpected differences in risk levels per feature between the different types of slope feature (i.e. cut slopes compared to fill slopes, etc.) and it has established that the average risk levels of the various facility groups adopted in the classification system used for prioritization for upgrading work (i.e. roads compared to buildings, etc.) can differ by several orders of magnitude (Wong et al, 1997). Improvements can be made in prioritization of slopes for the retrofit programme in line with these findings.

Research has shown the value of risk management in the control of development subject to landslip hazard from natural hillsides (Roberds et al 1997), for which problem the existing slope safety system requires substantial refinement, as explained earlier.

FEASIBILITY OF ESTIMATION OF RISK AND ESTABLISHMENT OF TOLERABILITY CRITERIA

Two of the three questions posed earlier about the feasibility of landslip risk management in Hong Kong will be considered in this section by reference to research carried out by GEO and others in Hong Kong: 'can landslip risk be reliably estimated?' and 'can landslip risk criteria be established?'. Research by GEO to develop a methodology for estimation of global and site-specific landslip risk in Hong Kong

by QRA began in 1993 and the first results are being published in 1997. As stated earlier, preliminary QRAs have been carried out for global risk due to landslips in old man-made slopes and from boulder-fall from natural terrain (Wong et al, 1997; Chan et al, 1997). Site-specific QRAs and risk assessment have been undertaken for landslip risk in a large squatter area and at a proposed public housing site threatened by landslips on natural terrain (Smallwood et al, 1997). The results of the QRAs and risk assessments are encouraging but limited. Thus, for want of reliable historical data on landslip detriment other than fatalities, risk has, at present, to be expressed solely in terms of probability of death, though it is known that risk means more to the stakeholders than fatalities alone. In regard to reliability, no uncertainty analysis or sensitivity checks have been published, hence QRA reliability remains to be demonstrated. In particular, uncertainties remain over normalization of landslip frequency data for rainfall.

With respect to risk tolerability, risk criteria have been published by the Hong Kong Government for potentially hazardous chemical installations (PHIs) (Hong Kong Planning Standards and Guidelines, 1996). The criteria are justified by reference to international norms. Research is underway by GEO to derive tolerability criteria for landslips and boulder falls on natural terrain from those adopted for PHIs. In due course the work will be extended to cover risk criteria for landslips in man-made slopes. The risk criteria proposed will require endorsement by stakeholders prior to their adoption in risk management.

To conclude, neither of the questions posed at the beginning of this section can yet receive an unqualified affirmative answer, but there are grounds for optimism.

MECHANISM FOR MONITORING THE EFFECTIVENESS AND EFFICIENCY OF THE COMPONENTS OF THE SLOPE SAFETY SYSTEM

In this section the third question posed by the risk management analysis will be considered: 'can landslip risk control, prevention and reduction options be evaluated in terms of cost and benefit?'. The global risk control and reduction options about which most is known are the component actions of the existing Slope Safety System (Table 1). Because some of the actions of the Slope Safety System have been in operation for twenty years or more, data exists to allow the calculation of the costs and benefits of its these component actions, where 'benefit' will be the attributable reduction in risk, as estimated by QRA, and 'cost' may be defined narrowly, as direct financial cost, or more broadly, to include indirect non-financial costs. The notional outcome of the component actions of the system, in terms of risk reduction, is indicated

schematically in Figure 7. The information needed to quantify the relationships shown on this figure is becoming available through QRA for the various elements of landslide risk (old slopes, new slopes, squatters, natural terrain, etc.). So far, as stated earlier, a preliminary QRA has been carried out for global risk due to old man-made slopes, suggesting that the risk reduction since 1977 due to the owners' upgrading programmes may be of the order of 50%. More such QRA work remains to be done for the other components of the system.

To respond to the third question, whilst evaluation has not yet been completed of the benefit individually of the component actions of the system, save for preliminary analysis of the retrofit programme for old slopes, and the costs of the component actions have yet to be calculated systematically, cost/benefit analysis would appear to be feasible.

It is therefore intended that future monitoring of the effectiveness, in terms of risk reduction, and the efficiency, in terms of costs per unit of risk reduction, of the Slope Safety System should rely upon regular QRAs and cost/benefit analyses (Geotechnical Engineering Office, 1997). The landslide database for these QRAs will be the historical database, supplemented by new data becoming available annually after each wet season. In this regard, a new division of GEO was created in 1996 for the investigation of landslips, staffed by firms of geotechnical consultants advised by their own independent experts. Their responsibilities include the examination and documentation of all landslips reported to GEO and the detailed study of some fifty of these each year. Some incidents will be 'near misses' in the sense of serious detriment, e.g. fatalities, being narrowly avoided. Such data is as important for QRA as actual detriment data but is very scarce. The documentation will thus make a valuable addition to the database on which the QRAs will draw, through the provision of comprehensive and reliable data. Detailed studies also provide evidence pertaining to any technical or administrative weaknesses in the system, thus facilitating system review.

CONCLUSIONS

There is evidence from analysis of fatal landslips suggesting that a significant portion of Hong Kong's landslide risk originated in the inadequacies of hillside development works in the post-war decades, along with lack of subsequent maintenance of constructed slope works. Site formation and subsequent maintenance by owners went largely unregulated by Government before the creation of the civil engineering unit in the building control office in 1972 and then the central policing body in 1977. By this date a very large amount of development,

both legal and squatter development, had already taken place on hillslopes, resulting in some 35,000 or more separate slope features of significant size. An upgrading programme for old man-made slopes in private and public ownership was begun in 1976 and has since proceeded broadly in risk priority order. About 10% of the estimated number of such slopes will have been upgraded by their owners by the year 2000, representing a possible reduction of some 50% in the 1977 risk level from old man-made slopes. A major safety clearance operation for hillside squatters was begun in the early 1980s and has resulted in the rehousing of more than 72,000 vulnerable people. The checking regime for new works introduced in 1972 (private) and 1977 (public) aims to maintain risk from slopes constructed after these dates at a low level. To achieve further risk reduction, educational campaigns were established in the 1990s to encourage owners to undertake slope maintenance and upgrading work and to warn the public to take precautions to limit their exposure to landslide hazard during critical periods.

The trends indicated in Figures 8 and 10 provide prima facie evidence of significant risk reduction in the past twenty years, which may be attributed to the Slope Safety System introduced progressively since the late 1970s. Assessment based on crude calculations indicates that the risk reduction effort has been cost-effective.

A process for handling risk to satisfy the needs of the parties involved, referred to as 'risk management', has become well-established in the hazardous industries and Hong Kong's landslide problem has been analysed using this approach. The application of the risk management process to the landslide problem in Hong Kong is desirable and appears feasible in principle based on pilot application of QRA and the risk management process. However, further work is needed to demonstrate QRA reliability and to derive risk criteria and obtain acceptance of them. Examination of the Slope Safety System in risk management terms has provided useful pointers for the further development of the system. For full application of the risk management process, risk reduction options should be evaluated in terms of cost and benefit. Measurement is, therefore, required of the effectiveness and efficiency of the components of the Slope Safety System in terms of risk reduction outcome and associated costs.

A commitment has been made to monitor the effectiveness and efficiency of the system regularly in the future through QRA and cost/benefit analyses and a new landslide investigation division, created in 1996, will supply annual landslide data for the QRAs. The division also contributes to system review through its detailed studies of landslips which provide evidence of any technical or administrative weakness in the system.

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APPENDIX

External Accountability Mechanisms for GEO

There are a number of institutional procedures by which the GEO is externally accountable. Starting with the Legislative Council, GEO is accountable through Motion Debates and Questions and by means of six-monthly reports to its Panel on Planning, Lands and Works, and, when called for by its Housing Panel, reports on safety inspections of squatter areas. Both panels conduct business in public. Select Committees enforce a higher degree of accountability but these are only convened when grave concern exists, such as that arising from the Kwun Lung Lau landslip in 1994 (Legislative Council, 1995).

Like other government bodies, GEO's work falls within the purview of the Ombudsman. Complaints to the Ombudsman concerning GEO have included appeals against GEO recommendations for squatter clearance from people wishing to be cleared and rehoused but not included in Housing Department's clearance plans, and vice versa. Statutory appeal procedures exist for persons wishing to contest the

Building Authority's private sector control actions based on GEO's advice and these have been used on a few occasions.

The Coroner's court provides a further forum for accountability, through its enquiries into the cause of fatal accidents. The prompt publication of GEO's forensic investigation reports which document the facts and infer the cause of fatal landslips and in which any GEO prior involvement with a site at which a fatal landslip has occurred is stated factually, provides another opportunity for public scrutiny. These reports are independently reviewed and reported on by technical persons of high standing internationally in the profession.

Accountability is also achieved through the media, whose role in Hong Kong of holding the civil service to account on behalf of the community is recognized by the administration, and through regular meetings with Legislative Councillors, District Board members, the geotechnical profession and five trade associations and groups representing geotechnical contractors and the property management firms.