The AsiaConstruct 19 Theme Paper-Hong Kong 2013.

Construction and Disaster Reduction-the Case of Hong Kong.

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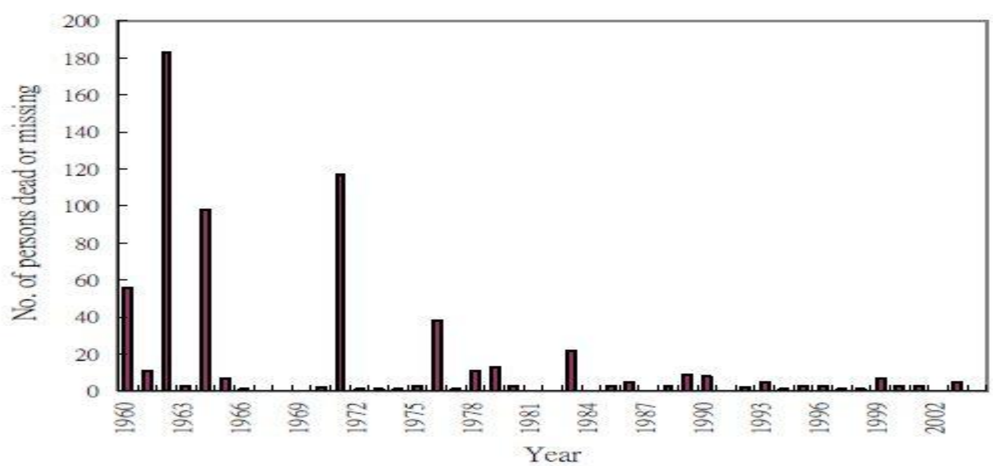
1. Introduction - Types of Disaster Mitigation in Hong Kong of relevance to the Construction Industry

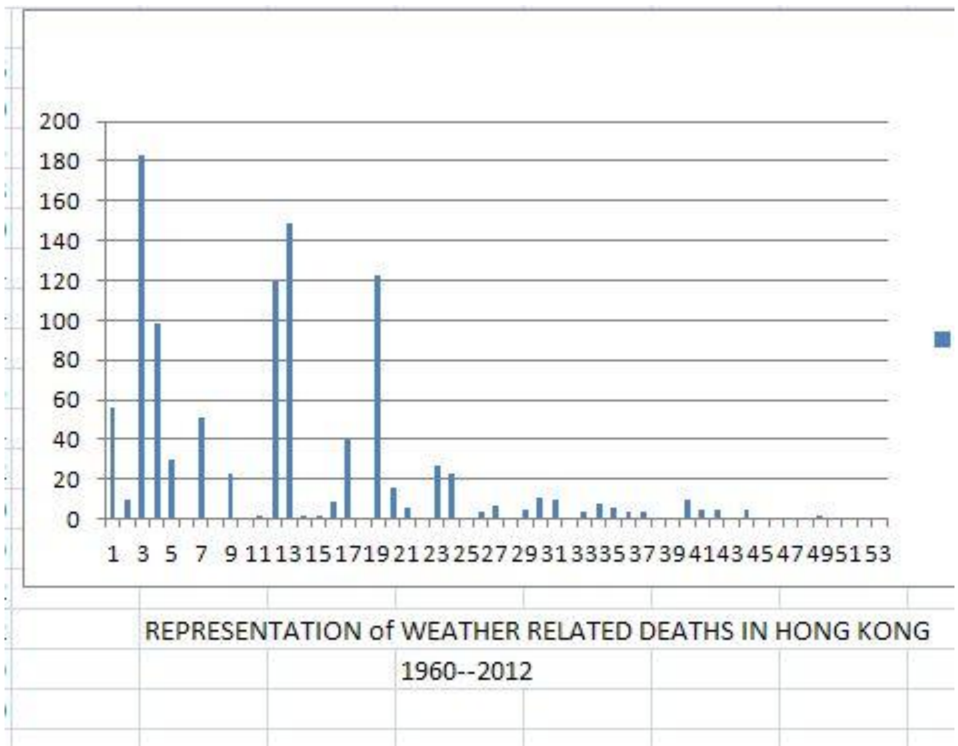
Compared to some other AsiaConstruct countries, Hong Kong is relatively disaster free. There has never been a destructive earthquake or a destructive tsunami for example. But typhoons and tropical storms cause a lot of water to fall on Hong Kong every year, 80% of it in the summer. The city is one of the wettest on the Pacific Rim. Heavy rainstorm induced serious landslides and floods were once commonplace, but over the last 20 years, the construction industry has gradually and painstakingly mitigated both threats to quite low levels, due to on going programmes of civil engineering work. These programmes are described below. The landslides mitigation programme was triggered by major disasters in 1972 and the flooding mitigation programme by much increased occurrences of flooding in the urban areas and the low lying land in the New Territories. This latter was due to the increased urbanisation of the 70s and 80s, including the building of several new towns in the New Territories (NT).

High velocity typhoon winds also have to be catered for by the construction industry, but there have been no cases of structural failure due to wind in modern times, implying that the wind design codes of practice are doing the job intended. The threat from high winds has already been effectively mitigated by the industry, therefore and this type of hazard is not discussed below. The design wind speeds assumed in Hong Kong, however, are given for the information of AsiaConstruct members. Very tall buildings must have their dynamic behaviour checked, because resonance conditions, or motions otherwise too extreme, can endanger the building and may cause local damage to cladding and fittings. Various technical remedies can be included in the design to ensure these structures never approach such undesirable states.

Construction sites can be badly affected by typhoon winds. All sites take precautions to batten down loose material and equipment as a storm approaches and check scaffolding and crane stabilities. Objects do sometimes ‘fly’ out of construction sites and cause deaths to pedestrians during typhoons.

The first histogram shows the loss of life in Hong Kong under “tropical cyclone” events since 1960 (Lam et al, 2005) including landslide deaths during tropical cyclones. Adding landslide fatality figures supplied to the authors by the Civil Engineering and Development Department (Lo D, 2013) , for those years when Lam et al showed no deaths, the second histogram was derived.





Note how low the numbers have become in the last 20 years. The reduction is almost certainly a function of the sustained long term government programmes of measures taken to strengthen slopes and prevent flooding in conjunction with the Government's Contingency Plan for Natural Disasters. The latter is a proven framework for weather related emergency responses triggered by sensor based warning systems and includes evacuations action when necessary .The emergency responsibilities of the different departments and agencies are detailed for the different cases of typhoons, rainstorms, floods and landslides. Emergency responses are kept simple by minimising the number of parties involved in each type of emergency and by delegating authority to those at the scene (Lam et al, 2005), (Emergency Support Unit, 2009). Loss of life is a function of hazard level and vulnerability level. The engineering programmes serve to reduce hazards and the warning and emergency systems serve to reduce vulnerability.

Building fires are a continuing cause of loss of life. Some losses occur every year, between say 8 and 25 across many individual annual incidents over the last 10 years, averaging about 12 per year (Fire Services Department personal information). Disasters punctuate this 'steady state' situation, such as the 1996 13-storey Garley building fire when 41 died and 84 were injured. As in all countries, the products of the construction industry are very much affected by fire safety regulations designed to minimise fire risks and fire damage. The tall buildings of Hong Kong present particular challenges in this regard, to the extent that the long term tried and tested fire safety rules do not really relate to high rise buildings over 30 storeys, say, including those super-tall buildings over 300m. Unlike landslides and floods research, for which the engineering predictive models are adequate, we do not really yet know how to best protect people in very high buildings against fire and we cannot reliably model how fires and smoke spread. Nor can we reliably model the escape behaviour of occupants of such buildings. Similar safety problems arise with the modern trend towards very large shopping malls. Large open areas with their often wide open shops are not that safe. Also adding significantly to fire dangers are the problems of evacuating underground railway systems.

The earthquake threat is interesting in the case of Hong Kong. The industry has so far ignored the earthquake threat and taken no action to mitigate the effects of one. It is true, of course, that no earthquake has yet caused anything but the slightest of damage throughout the 172 years of the modern history of Hong Kong. Nevertheless, Hong Kong is situated within a region of moderate seismicity and most cities similarly placed around the world, do have design codes intended to mitigate loss of life and damage to buildings. This is discussed further below.

Daya Bay Nuclear Power Stations Potential Disaster

There are two nuclear power stations about 1km apart, on the Mainland China coast, only 45 km to the east of downtown Hong Kong. The UK Atomic Energy Authority has assessed the risk to health of the Hong Kong people as "lower by a large margin" than everyday risks in Hong Kong (Emergency Support Unit, 2012). There are no implications for the Hong Kong construction industry as long as no disaster occurs at the plants. As such, further discussion is outside the scope of the paper.

Structure of the Remainder of the Paper

Immediately following, are four Sections, 2 to 5, discussing landslides disaster mitigation, flooding mitigation, protection against earthquakes and protection against fire respectively. In each case the threat is described and the worst case scenario design conditions applying to structures and buildings are given. In the case of landslides and floods, the nature of the mitigating civil engineering work programmes undertaken are also described, in Sections 2 and 3.

The earthquake threat to Hong Kong is currently being formally debated. This situation is described in Section 4. In the case of fire, the strategy employed in Hong Kong to minimise fire damage to life and property is described in Section 5.

Section 6 provides information on the research taking place in Hong Kong relating to these four disaster areas. It is stressed that more research is needed in the case of fire, in particular.

Section 7, to round off the paper, briefly outlines the scope of the government controlled emergency actions to meet danger and disaster contingencies.

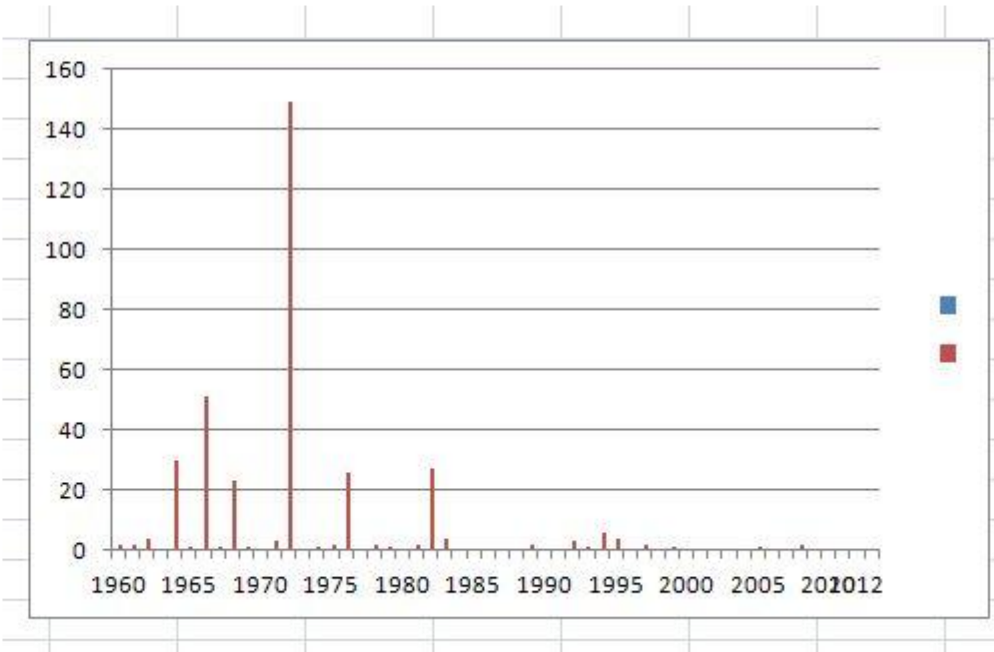
The authors venture some concluding remarks in Section 8.

2. Landslides Mitigation

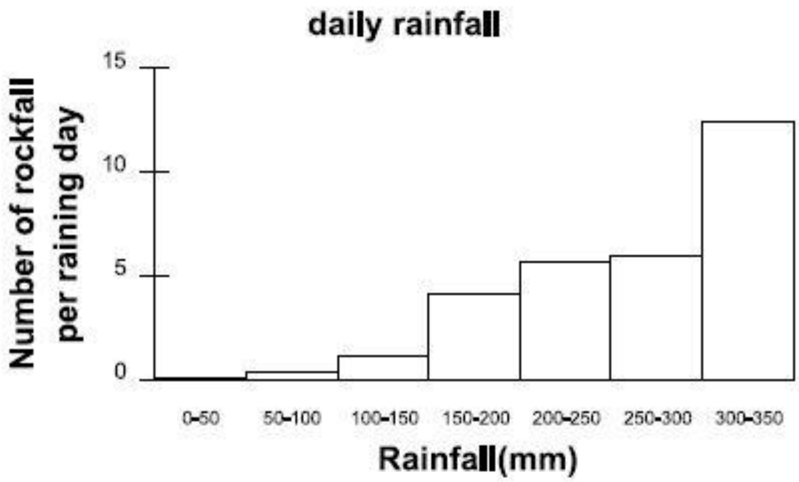
Landslides –The Threat

About 70% of the area of Hong Kong is mountainous and it is common for housing, commercial premises and roads to be under the threat of landslides. 60,000 man made slopes have been catalogued by the Geotechnical Engineering Office (GEO). Each year, on average, there are 300 reported land slips, rarely of much consequence, usually following periods of heavy and continuous rain. Steep and smallish catchment areas make for rapid run off concentrations.

354 deaths from landslips have occurred in the 50 years since 1960 (Civil Engineering Development Department provided personal data), about 7 per annum. The graph below, however, shows how few have occurred in the last two decades.



Boulder falls are also commonplace. For the 15 years 1984 to 1998, reportable rock falls from natural slopes averaged 25 per annum leading to 1 death per annum. Rain is also the main factor here. The chart gives the number of falls to be expected on a particular day in relation to rainfall intensity. (Chau et al, 2003)



7. The average number of rockfall per each raining day versus the daily rainfall

Rapid population growth in the 50’s and 60’s particularly, forced urban development into areas of hilly terrain, leading to the formation of many man made cut and loose fill slopes. These have proved much more likely to fail than natural slopes.

A watershed moment was provided by two major landslip disasters in 1972, in which 138 people died. This led to the establishment of the Geotechnical Control Office (the Geotechnical Engineering Office (GEO) of today) and the Landslip Preventive Measures Programme (LPMP). This major long term on-going programme involved the cataloguing of all man made slopes, their inspection, rigorous risk assessment and strengthening/maintenance where necessary to ensure minimum Factor of Safety criteria are met(see below). Selected potentially life threatening natural slopes are also monitored.

The 1972 disasters are illustrated by the photographs below. A spectacular building slip resulted in 67 deaths. One whole multi-storey building was carried downhill and tilted over.

The second photograph compares the before and after situations for a second 1972 disastrous event. 71 died in this landslide. The temporary housing areas at bottom centre can be seen completely submerged in the debris.


宝珊道
1972 Po Shan Road Landslide
67 killed and 20 injured
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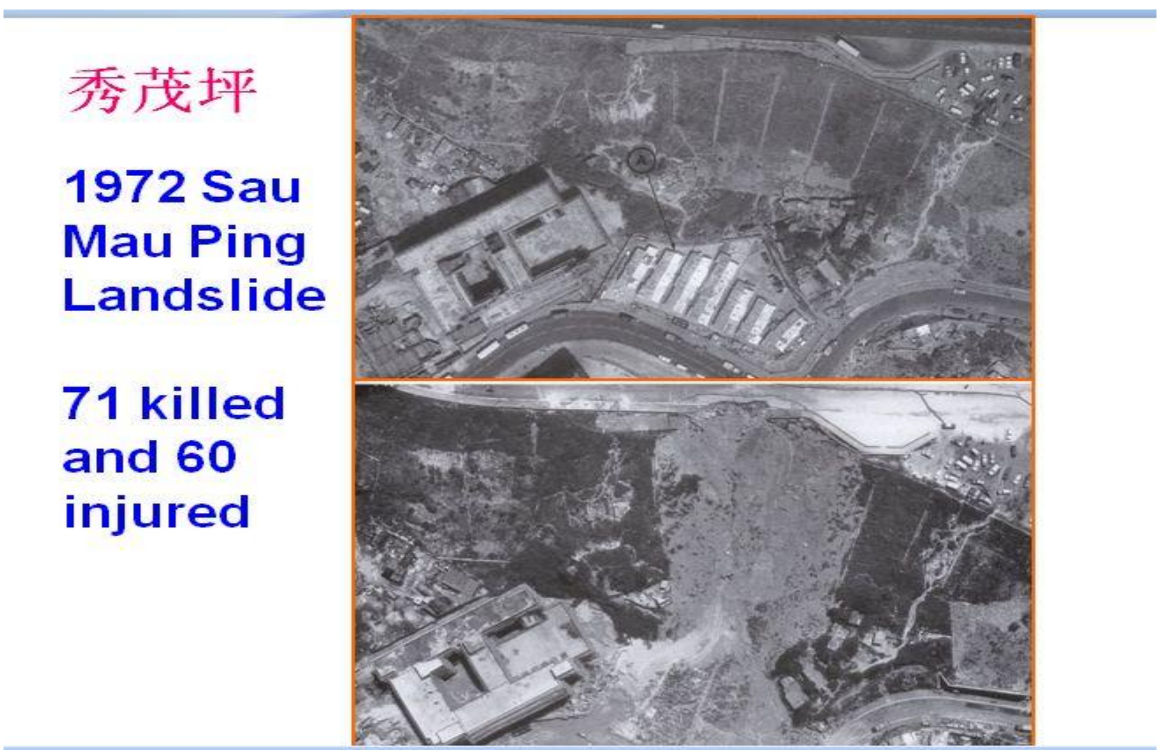
秀茂坪
1972 Sau Mau Ping Landslide
71 killed and 60 injured

In 2009, a new Landslip Prevention and Mitigation Programme began (LPMitP), superseding the LPMP . Natural slopes are now routinely included, in recognition of the fact that urban developments have pushed further out into mountainous areas, due to shortages of land supply.

Landslides – Risks and Design Criteria

All man made slopes must achieve a minimum specified Factor of Safety (FOS) against slip. The value for any particular slope depends upon a 'risk to life' assessment and an 'economic loss' assessment. If any one of these two assessments is classed as 'high risk' the FOS value must attain the stringent level of 1.4 under conditions of a 10 year return period rainfall event.

If none are 'high risk', but any one of the two is 'low risk' the FOS must reach 1.2.

Even if both risks are classed as negligible, the FOS value must still be greater than 1.0 under 10 year rainfall event conditions.

The FOS of a slope is defined as the "ratio of the maximum shearing strength of the soil, i.e. its maximum shear resistance, to the actually occurring shear stress in the soil along the critical slip surface". The critical slip surface is that which produces the least FOS value. The shear resistance property of soil is weakened as water content increases and this soil nature dependant value must be assessed before the FOS can be calculated, allowing for the absorption of the rain water by the slope.

Ten year rainfall data for Hong Kong, in mm/h, is related by a standard curve to the time taken by surface runoff water to concentrate. Different catchment areas have different concentration times. A slope in a five minute catchment area must assume a 220 mm/h rate of rainfall, whereas 125 mm/h is sufficient for a twenty minute catchment. (10 year rainfall is very roughly 80% of 50 year return rainfall and 65% of 200 year rainfall. This is mentioned because trunk drainage design, to mitigate flooding (below) is based on 200 year events and urban drainage design assumes a 50 year event. In fact, for rainfalls exceeding the 10 year return levels, the FOS value would reduce somewhat but actual slope failure would be highly unlikely.

An additional requirement, regardless of rainfall levels, is that any slope classed as 'high risk to life' must have an FOS of 1.1 minimum against the worst possible groundwater table predictions.

Landslides Mitigation Actions

As laid down by the LPMP, for man made slopes which existed before 1977, slope stabilising engineering measures are taken on site when FOS assessments fail to meet specified levels. Man made slopes constructed since 1977, have been automatically built to the required FOS standards.

The LPMP involves inspection of most slopes every year, strengthening work where required and automatic monitoring of movements of high risk slopes. The two monitoring devices in common use are the 'inclinometer' and the 'piezometer,' the readings of which are obtained either manually or automatically transmitted to a central computer.

The LPMP, which ended in 2010, started in 1976. After cumulative expenditure to date of over 16,000 million HK dollars, the failure probability of all man made slopes today is less than 25% of the failure probability which existed in 1977. Because progress up to the 1990s had been slow, private sector resources were then recruited. About 4,000 government owned slopes have been upgraded since 1995 (of about 4,900 since 1977) and about 4,800 privately owned slopes have been screened (of 5,200 since 1977).

Since 1995 annual slope maintenance and strengthening has averaged about 1 billion HKD p.a. To give some perspective, this is of the order of 3-5% of all civil engineering infrastructure spending in Hong Kong. The graph immediately below illustrates the marked acceleration which occurred in 1995.

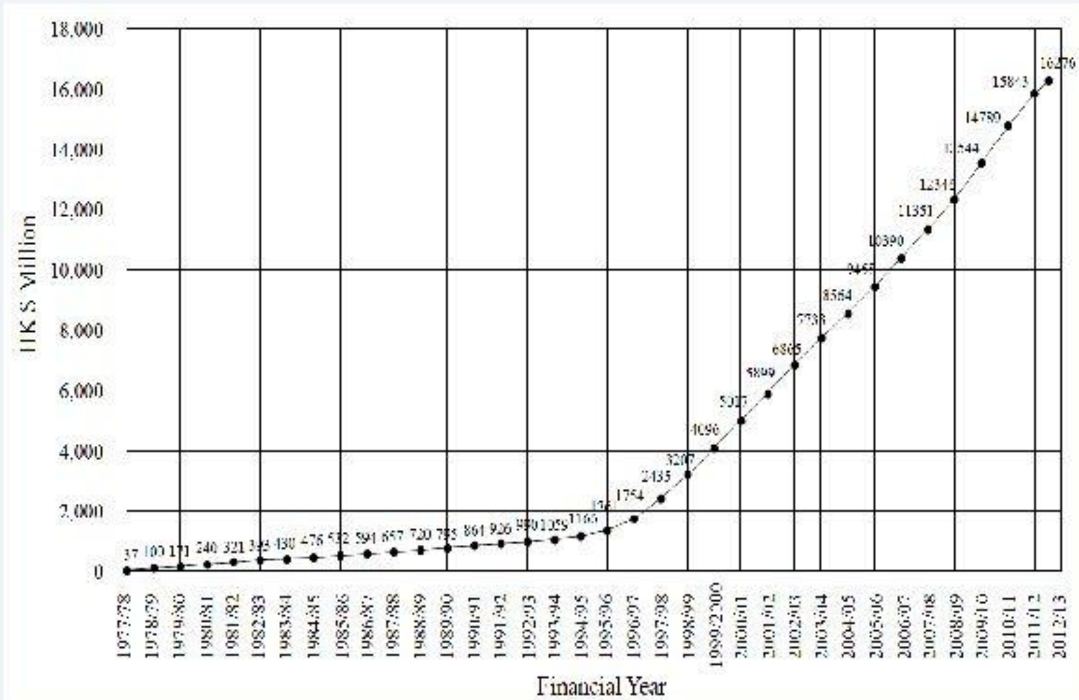

Figure 6 : Cumulative Expenditure on Landslip Prevention and Mitigation Works and Studies by GEO as at 30.9.2012

In relation to private slopes, 2,700 'dangerous hillside ' orders have been issued to the owners, requiring investigation and the necessary upgrading work. [Report No. 2/2012 on Landslip Prevention and Mitigation Studies and Works. Geotechnical Engineering Office (GEO)]

The Landslip Prevention and Mitigation Programme (LPMitP) superseded the LPMP in 2009, with some slight overlap. The new programme continues the work of the LPMP but now also includes natural hillside slope hazard mitigation. The plan continues with man made slopes (specifically, the upgrading of 150 p.a. government owned and the screening of 100 privately owned) and adds a target of 30 hillside catchment natural slopes per annum (HLCs). About 2,700 of the latter have been identified. HLC hazards include debris falls and boulder falls. Slope stabilization itself, would be too expensive and environmentally undesirable so HLC landslide risk mitigation measures involve the provision of debris traps and barriers. About 40 of these slopes have been treated since 2009.

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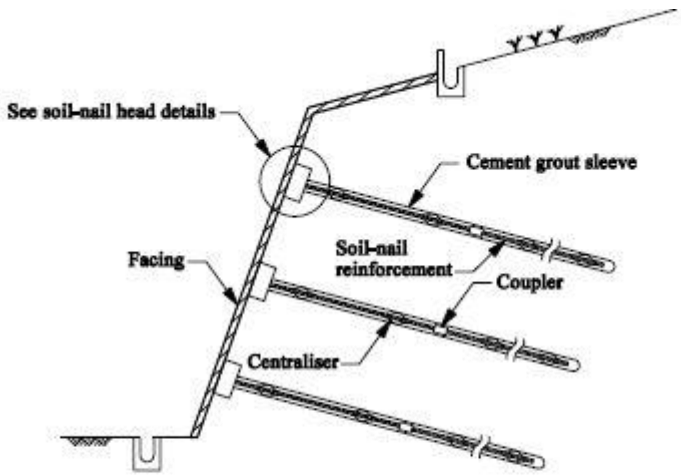
In Hong Kong, much the preferred method of <u>slope strengthening</u> involves the application of 'soil nails'. Soil nailing has been used for about 80% of the slopes strengthened in Hong Kong. A circular hole of the order of 100-250 mm diameter is drilled 10-20 metres into the slope. The hole is then filled with a steel reinforcing rod cast in concrete grout under some pressure, so as to completely fill the hole and produce a strong frictional bond between the grout when hardened and the surrounding soil. Any tendency of the soil to slide along internal planes at points within the slope (i.e. an incipient landslip) is resisted by the nail-soil frictional interface. The nail resists being pulled out of its socket by the soil movements, thereby minimising /preventing soil movements in its vicinity and obviating large scale global slipping. Soil nails are installed across the whole slope face in a regular pattern such that nails are about 1-3 metres distant from each other.



Typical Cross-section

Many slopes are protected by keeping them as dry as possible, so that the soil does not become saturated by directly impinging rain, and thereby lose some of its shear strength in heavy continuing storms. Such slopes are coated with an impervious membrane. This is often shotcreted concrete but a compound known as chunam is also used. Neither of these protective measures look very attractive, however, and ‘greened’ man made slopes have begun to appear recently.

‘Greened’ slopes are provided with drainage channels to carry away surface rainwater reaching the slope. Between the channels appropriate vegetation or grass cover is provided.

Slope Stability Warning Systems

As stated above, some slopes classed as 'high risk' are instrumented with piezeometers and sometimes inclinometers. A change in an inclinometer angle usually means that the earth has shifted in position at that point giving warning of a possible major slip. Piezeometers are water pressure gauges also useful for monitoring water table levels. The outputs from these instruments, manually read or fed back automatically to a central computer are monitored. These instruments have been in use in Hong Kong for over 30 years. New types of instrument, including linear transducer tension crackmeters, point located devices which record displacement , rotation and settlement and GPS based systems to detect slope movement in three dimensions were all used in real time systems developed by Mills et al (2008) for four hillside sites in Hong Kong. This was a joint Ove Arup and GEO project including involvement of the Hong Kong Polytechnic University (HKPU) with respect to the GPS systems.

Rainstorm warnings at various colour levels (black, red, amber), indicating degrees of severity and landslide risk, are issued on radio and television and government websites. Owners of slopes understand how the specified warning 'colour' relates to levels of landslide risk.

3. Flooding Mitigation

The Nature of the Threat

With an average annual rainfall of 2,400 mm, Hong Kong is amongst the wettest of Pacific Rim cities. 80% of the rain falls over 5 summer months. In June, 2008 over half of that average annual amount fell in one month. Heavy prolonged rainstorms induce floods, as well as landslides.

Tropical cyclones are common summer time features contributing both rain and storm surges. Since 1954 there have been 22 storm surges averaging 3m above chart datum, or 1.6 m above mean sea level. The highest ever, in 1937, was 6 m above datum. The most recent, in 2008 was 3.53 metres above chart datum due to Typhoon Hagupit. In 1962, 3.96 metres above datum was recorded due to Typhoon Wanda (Lee at al, 2010 est.), one of the most devastating in the history of Hong Kong , when 30 were killed and about 72,000 made homeless.

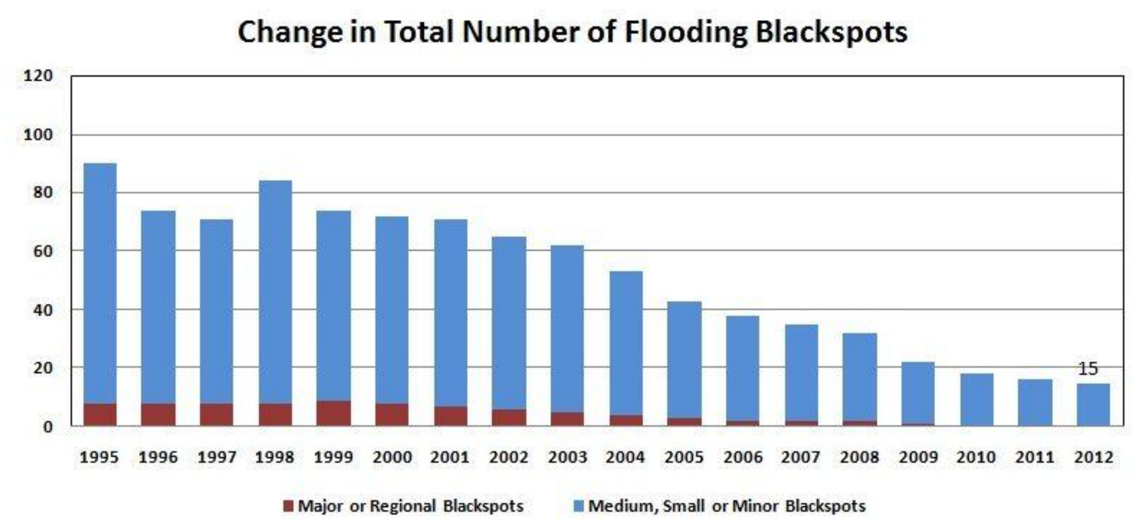
In the past, the flooding hazard level had been high for coastal areas, much of the Kowloon peninsula and extensive parts of the rural New Territories in the northern part of Hong Kong. The latter region is mostly flat with many villages at low levels.

Rapid urban new town development occurred in these flat rural areas during the 80s and higher up the hillsides in the established urban areas. The additional paved areas increased the levels and intensity of surface runoff. Natural watercourses in the rural areas, at the same time, were often degraded by construction and other wastes and their flow capacities reduced. The older urban drainage systems were subjected to rapid rainfall run off quantities from higher up the slopes, rainfall which had previously been retained by the upper slopes and released only gradually.

Actions History

In September 1989, the Drainage Services Department was established, among other things, to tackle flooding problems systematically. A flood prevention strategy was devised and Drainage Master Plans (DMP) were established after much study for 8 flood prone regions. Under these long term storm-water drainage improvement measures, about 21,800 million Hong Kong dollars had been spent between 1989 and 2012 with a further 13.6 billion of expenditure still in the planning and design stages.(DSD personal information) Such expenditure, varying each year (In 2004/5, 2.6 billion was spent for example) is about 3-6% of Hong Kong’s total construction industry annual turnover in civil engineering work, representing a steady and easily manageable demand on the civil engineering construction industry. The nature of the protection work, discussed below, consists of (i) relatively small scale operations such as routinely ensuring max flow for existing drainage through cleaning out maintenance, (ii) larger scale work to greatly increase watercourse flow capacities by such as river training works and others (see below) , and (iii) four major upland water interception schemes involving large diameter tunnels through the mountains. Their purpose is to intercept intense storm run off water from upland levels, before it reaches and overloads those older urban drainage systems. The Lai Chi Kok transfer scheme is described below as an example. In addition to these four above, a West Kowloon storm-water drainage improvement scheme was completed in 2012.

The effect of these measures had reduced the number of flooding black-spots by half, from just under 80 in 1995 to just under 40 by 2006. By 2012 the number was only 15. It is clear that significant benefit is being derived from the expenditure.



It is essential to appreciate that the above work and its maintenance and continuing efficiency is backed by legislation in the form of the Land Drainage Ordinance. This gives the DSD power of access to the 'Main Watercourses', which the DSD itself designates and receives approval for, and the power to order the removal of any works, whether on private land or not, which interferes with main watercourse flows. Five approved Drainage Authority Area Plans exist under which 'main water courses' are delineated. Without that legislation it is unlikely that implementation of the DMPs would have been successful. In the past, many developments took place in the flood prone New Territories areas which would block or restrict drainage courses on the one hand and increase surface run off flows on the other.

The DMPs of the early 1990s, now mostly implemented just over 20 years later, also took account of the SAR's Outline Zoning Plans (OZP), and were produced after formal Drainage Impact Assessments had been submitted and the difficulties uncovered ironed out.

Currently a review is being made of all the DMPs. This is because, major new infrastructure and building projects are planned or are under way in Hong Kong , schemes which impact significantly upon existing drainage provision and were not anticipated when the DMPs were drawn up. The influence of climate change on sea level is also being taken into account in this review. The Port Works Department, in relation to its own future construction planning is also making a climate change effect assessment (see below).

Flooding Risk Levels and Design Criteria

Since the open sea receives the storm-water flow, its maximum assumed level is important for storm-water drainage system design. Allowing for storm surges, maximum design sea levels are as high as 4.75 m above datum in Tolo Harbour and Deep Bay (Chui et al, 2006). Only the surge of 1937 has exceeded this level. This parameter has a big effect on the extent to which gravity can be utilised for drainage and the capacity of pumps required when otherwise.

As to rainfall intensities and times of flow concentration (loosely related to catchment size), a return period of 200 years is assumed for the design of urban trunk drains and 50 years for urban branch drains and the main rivers and rural channels (DSD website). In fact 50 year rainfall is as much as 75% of 200 year rainfall for big catchment areas, say, and about 90% for smaller ones.

Stormwater Facilities	**Return Period (years)**
Urban Drainage Trunk Systems	200
Urban Drainage Branch Systems	50
Main Rivers and Rural Drainage Channels	50
Village Drainage	10
Intensively used Agricultural Land	2 - 5

The important max sea level assumption may have to be updated due to the effects of climate change, as indicated above. The Port Works Division (PWD) of the Civil Engineering and Development Department is also vitally concerned with sea levels and with maximum wave forces exerted on its many marine structures. Extreme sea levels currently used by PWD for design are published in the manual PWDM Pt.1. At Tai Po Kau , for example, the 200 year return sea level is given as 4.6 metres above datum and 4.3m for the 100 year event. (This compares with the Tolo Harbour figure of 4.75 quoted above. Tolo Harbour is a location where the highest sea levels are experienced.) The PWD currently bases its design loadings on i) a 100 year wave combined with a 10 year extreme water level and ii) a 10 year wave combined with a 100 year water level.

As to climate change effects, the study "Review of Studies on Climate Change and its Implications on the Design of Coastal Structures" is being conducted, to be completed in 2013. PWD design manuals will be updated in light of the findings in the following year. (personal communication from the Civil Engineering Development Department)

Mitigation Activity- DSD Flood Prevention Strategy

In addition to the provision of storm-water pumping schemes to deal with storm flow directly at flood prone areas, the programme of flood mitigation work can be grouped into four categories. (DSD website)

Systematic preventive maintenance.

A basic essential is the preventive maintenance of all drainage components, both man made channels and culverts and natural watercourses, to ensure maximum flow capacity is maintained in readiness for severe rainstorms. This involves routine inspections and the clearance of debris, repairs to drains, their de-silting and the dredging of rivers.

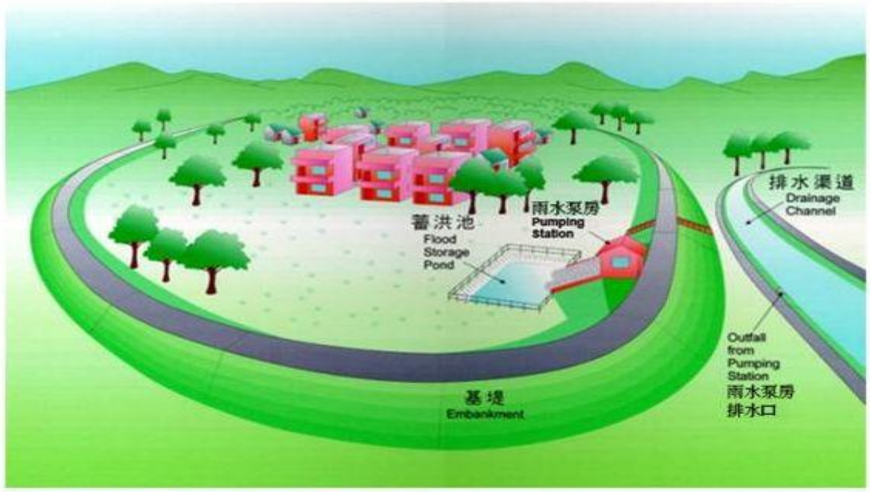
River training works.

A natural river can normally cope with a 2-year rainstorm without flooding. To cope with more extreme events a number of training works have been completed. These include straightening, widening and lining. Most of the rural flood prone areas are now much less susceptible to flooding than before. As a very rough rule of thumb, impressively, the river training work has probably at least doubled the capacity of the original rivers and streams in providing a 50 year storm capacity.

Completed river training works at Ng Tung River near Tin Ping Shan, Sheung Shui

Village flood protection

35 rural area villages are in low lying areas, liable to flooding in spite of the river training works. Most of these have now been protected by an encircling embankment. Drainage inside the bund is led to a concrete sump pit and pumped to a water channel outside the bund. This internal drainage is designed to cope with a 10 year storm. These systems are working well.



Schematic layout of a village flood protection scheme

Schematic layout of a village flood protection scheme.

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<u>Urban drainage systems</u>

Because of the density of the urban infrastructure of Hong Kong, it is often prohibitively expensive and disruptive to upgrade 100 year old drainage systems to cope with the 200 year rainstorm. Urban area flooding has been very common in recent decades but major relief schemes have now much reduced these incidences. These schemes work either (a) by smoothing off the urban upland <u>peak flows</u> reaching the urban storm-water systems or (b) by intercepting the upland flows at higher levels and running them straight out to sea.

The first is accomplished by building hidden, underground, <u>storage tanks</u> big enough to retain a sufficient volume for a while, enabling gradual release of the stored water later. This smooths out the downstream flow rate by removing the peak flow. Three such tanks were built, the largest as much as 100,000 cubic metres in size. The underground tanks are well disguised. One at least is topped off with a football pitch.

This solution was adopted, as an integral part of the West Kowloon drainage improvement scheme, to overcome the flooding problems of Mong Kok, one of the areas of greatest population density anywhere in the world.

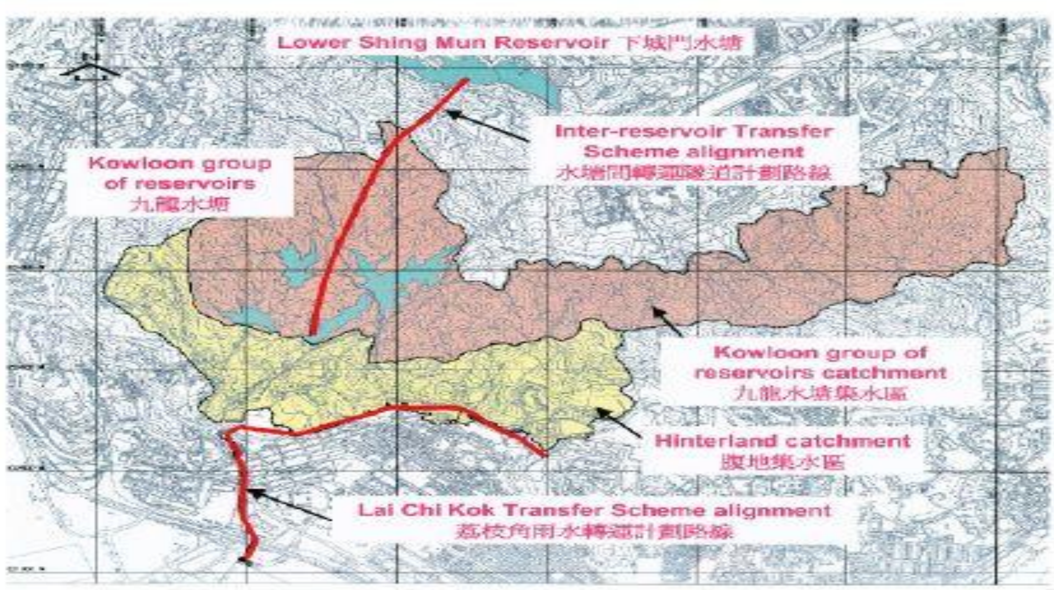
Four major schemes have just been completed taking the second approach. A large diameter <u>interceptor gravity flow tunnel</u>, running eventually straight out to sea, is laid along a contour at the base of the hill slopes but above the bulk of those older urban areas built on the coastal flats and on reclaimed low level ground. The interceptor tunnel intakes are designed to accept only those flows large enough for the tunnels to be self cleansing. Normal non storm upland rainwater flows are allowed to enter the urban drainage network because such flows cause no overload. (Low flows in large tunnels are to be avoided because the inevitable silting up leads to more maintenance to maintain tunnel hydraulic efficiency)

These interceptor tunnel schemes are economical because the water flow is gravity driven and maintenance access to the tunnels is simple, since they are dry under normal conditions and because of their ample size (4.9 metres in diameter for the Lai Chi Kok scheme below).

The Lai Chi Kok Drainage Interceptor Tunnel Example

As an example of an interceptor scheme, the Lai Chi Kok drainage interceptor tunnel is described herein (Ip et al, 2009). Construction took place between November 2008 and October 2012 at a cost of 1.77 billion HK dollars.

The purpose of the scheme is to reduce flooding in urban West Kowloon. Flooding often occurred following heavy rainstorms with traffic disruption, property damage and danger to life. The problem had become much worse in recent decades because many hinterland developments have converted once natural ground into paved areas producing large volumes of run off at times. The scheme intercepts upper slopes runoff plus any overflow gathered up from the Kowloon reservoirs to prevent the urban drainage system from being overloaded.



f (a)

The scheme essentially consists of a 2.5 km long, 4.9 metre diameter branch tunnel, with 6 drop intakes, A to F, intercepting water from a 160 hectares hinterland catchment area assuming a 200 year storm. The branch tunnel runs right to left on the diagram above, adjacent to the yellow hinterland area This tunnel falls about 9 metres from a height of 21 metres above chart datum to a stilling basin terminus with a mean gradient of about 0.4% ; and (b) a main tunnel 1.2 km long also of 4.9 metres diameter. The water drops 40 metres from the stilling basin into the main tunnel which takes both the branch tunnel water and the overspill from the Kowloon reservoirs water, straight to the harbour, via what is an inverted siphon under 40 metres of pressure head. The main tunnel runs very roughly at right angles to the direction of the branch collecting tunnel and it is set much lower to pass below the built up old urban areas (see the red line on the map). On reaching the harbour's edge the drainage flow ascends a 40 metre riser shaft before entering the sea.

Interesting challenges played a part in many of the final scheme decisions. The various existing

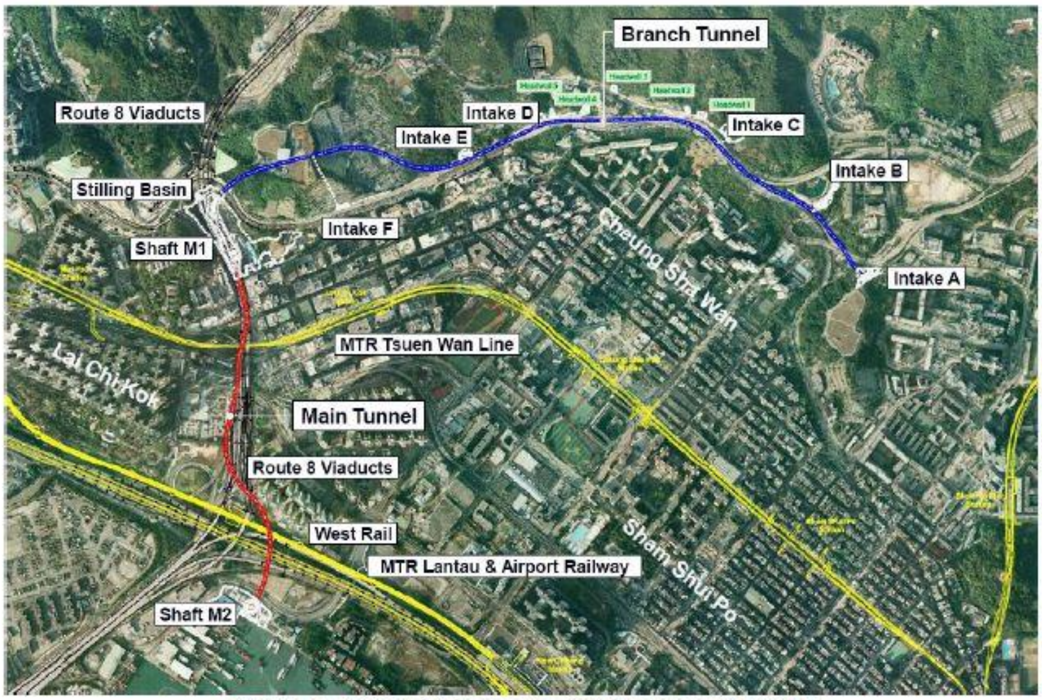


Figure 1. Tunnel Alignment and location of Works

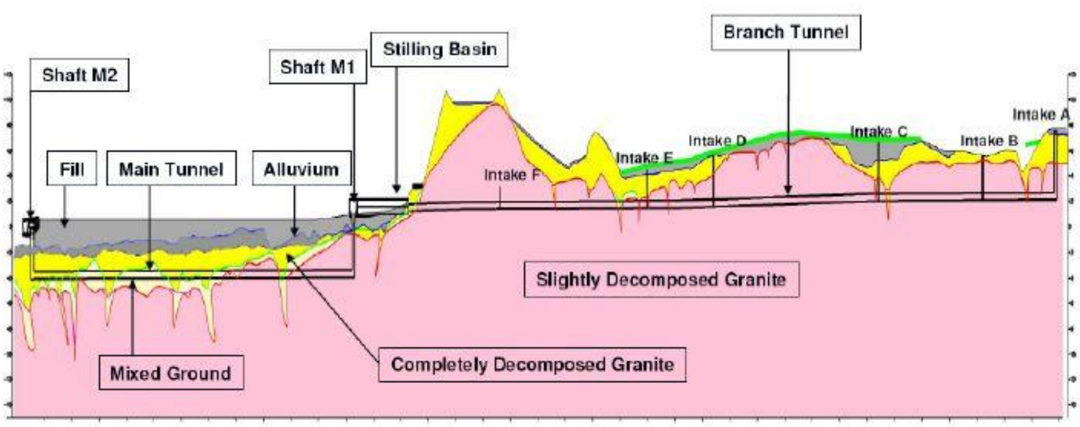


Figure 2. Inferred Geological Profile and Vertical Alignment (Vertical Scale Schematic)

hinterland built developments limited the possible locations for the branch tunnel intake shafts A to F. This factor largely determined the line of the branch tunnel, although a horizontal line shift was also caused at one point to avoid long raking piles supporting a roadway. The vertical alignment of this tunnel was affected by a twin 2 metre diameter water-main supplying West Kowloon. The vertical separation initially was an unacceptably close 1.7 metres, duly increased to 5 metres (still close in engineering terms for a 4.9 metre diameter tunnel), but the absolute maximum possible within the bounds of tunnel hydraulic efficiency.

To avoid all the building piled foundations, three existing rail lines and highway viaduct foundations, a depth of 80 metres below datum was initially chosen for the main tunnel to provide sufficient rockhead. At that depth, however, highly fractured zones were found in the rock. To avoid the difficulty of constructing the outlet riser under the high groundwater water pressures thereby expected, a big reduction to only 40 metres depth was necessary to ensure the outlet riser was wholly above the fractured rock zone. The tunnel line had then to be adjusted at several locations to avoid existing piled foundations, resulting in some tight curves for negotiation by the Tunnel Boring Machine (TBM) during construction.

The main tunnel diameter would have been 6.4 meters, and not the actual 4.9 metres, if all the reservoir overspill were to have been transferred to the Lai Chi Kok scheme. In 2002, however, after consultation with the Water Supplies Department, an alternative was designed with water conservation in mind. It was found that only 25% of the 200 year storm reservoir overspill needed to be taken out to sea by the LCK main tunnel, since 75% of it could be taken to a further reservoir in the Kowloon system, still with some capacity, and not simply discharged to sea and wasted. The fact that both branch and main tunnels in the LCK scheme are now of the same diameter has obvious cost advantages. The one TBM machine was used for both tunnels and there are identical segmental tunnel linings.

Monitoring & Warning, Flood Risk Management

Because catchment areas are both small and steep, problems can arise rapidly in 1-2 hours, even in as little as half an hour in urban districts. Real time monitoring of water levels at critical places is essential, if flood warnings to the public and emergency teams are to be issued in time.

Water control devices to divert flows or to smooth flows out downstream can also be rapidly activated. Most are automatic and some manually operated.

The real time device readings are fed back to central control for the issue of warnings. Siren warnings at the sites of the monitoring instruments often sound out automatically. Instrumentation exists at 80 locations across the territory, including rainfall gauges, water level probes and 4 tide gauges. Some monitoring stations can send back photographs and some are solar powered. Fixed line feedback systems were prone to interruption and other unreliabilities and have largely been replaced by a 2.5G/3G mobile communications wireless system.

The DSD operates a 24 hour hotline for the public to report unexpected flooding events (eg drainage blockages) or any other problem. Teams are available to respond very quickly to such calls . The DSD has a preventive maintenance programme to ensure the continuous efficiency of all types of drainage conduits, hydraulic structures and mechanical water flow control mechanisms. Many of the latter can be remotely operated from a central control station.

One of the DSD disciplines is to ensure that the whole system is routinely checked on the day following a severe rainstorm and remedial action taken where necessary. Often debris, for instance, gets carried into the system becoming jammed and degrading effectiveness.

Underpinning these activities, is the ‘Land Drainage Ordinance’, which allows DSD instant access to all DSD designated Main Watercourses, as stated above, whether or not they lie on private land.

4. Protection against Winds and Earthquakes

The Threat

The threat relates mainly to the stability of building and civil engineering structures. In fact, the design of structures to resist high winds is well understood and there is virtually no threat to speak of from this cause nowadays. Very tall buildings and long span bridges do have to be checked for excessive wind induced vibrations and resonance effects but there are well proven ways of ensuring any potential problems are avoided. The big suspension and cable stayed bridges in Hong Kong and some of the very tall buildings are instrumented and continuously monitored, but this probably has more to do with detecting local degradations and preventive maintenance actions than any disaster expectation.

Nevertheless wind speeds can be very high and it is necessary to ensure that the maximum forces exerted on buildings are accurately estimated.

Earthquakes are different, potentially dangerous to both structures and the stability of slopes. Earthquakes in Hong Kong, however, are usually very slight. There has been minor structural damage on only one occasion in the 170 years of the city’s period of substantial settlement. But 170 years is not all that long a time in geological terms, and China’s classification system does put Hong Kong within a region of moderate seismicity.

Earthquake tremors are felt every year in Hong Kong but they are almost invariably less than Magnitude 4. In general, earthquake damage does not occur in Hong Kong. There is no current requirement for earthquake resistant building design. Nevertheless a 7.4 magnitude intensity did occur in Hong Kong in 1918, due to a Magnitude 10 earthquake centred 300 km distant. Cracks occurred in some structures and a school on Hong Kong Island had to be relocated. In

1874, an earthquake was centred only 30 km from Hong Kong but at only M=5.7 was not damaging.

The question of earthquake resistant building design, however, has now arisen, probably partly as a consequence of the reversion of sovereignty to China. Earthquake resistant design is routine in the province of Guangdong to which Hong Kong geographically belongs. Seismographic evidence, indeed, suggests that Hong Kong lies within a region of moderate seismicity (Ove Arup & Partners(2007)) and buildings in future are very likely to be designed accordingly. Consultation within Hong Kong is taking place right now, on the appropriate earthquake resistant design requirements for new buildings and whether existing buildings should be strengthened.

Risks and Design Criteria

<u>Wind Forces</u>

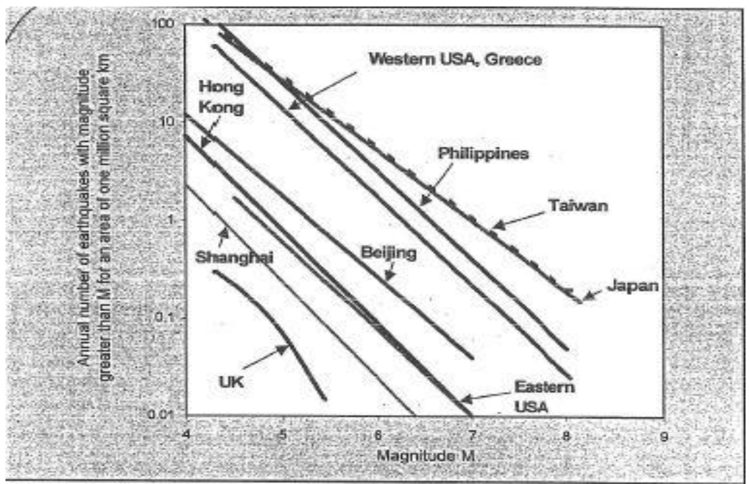
Design wind speeds are based on a 50 year return period. At a height of 90 m (say 30 storeys) buildings are to withstand a steady speed of 49.2 m/sec and gusts up to 3 seconds long at 68.5 m/sec. To cater for super high buildings, the figures are 59.2 and 78.7 respectively at a height of 500 metres. Structural engineers convert these speeds into pressures and suctions and thence force distributions over the whole building, the force values depending also upon building orientation and geometry. The building shear walls, columns, floor slabs, beams and foundation are designed to be strong enough to carry those forces.

<u>Earthquake Assessment</u>

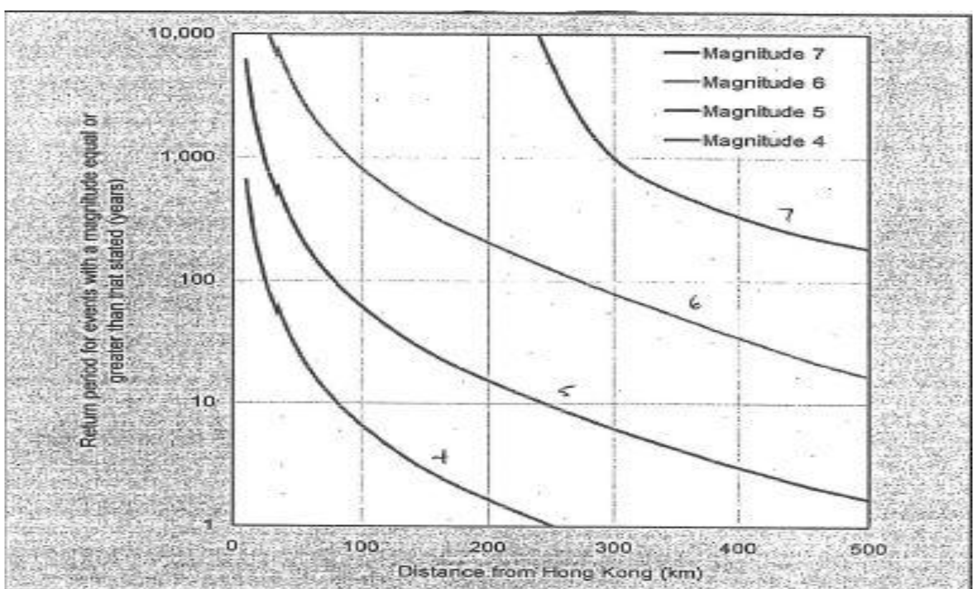
Since China places Hong Kong within a zone of moderate seismicity some researchers in Hong Kong, have studied the background evidence relating to risk of major earthquake and others have examined the vulnerability of existing structures in Hong Kong to a sizeable earthquake strike (Xu et al 2001). The Buildings Department commissioned consultants Ove Arup to address the issue. Their report was produced in 2007 (Ove Arup (2007)) and is currently the subject of widespread consultation.

Based on the records of earthquakes detected in Hong Kong and centred within 500 km, the report concludes that seismicity in Hong Kong is similar to that of the eastern USA seaboard, considerably greater than that of the UK and somewhat less than that of Beijing (see first figure below, taken from the report). The ordinate represents the annual number of earthquakes experienced at the various places; the abscissa, the magnitudes as felt at those places). The second figure below, also taken from the report, for earthquake magnitudes of 4,5,6 and 7, relates epicentre distance from Hong Kong to return period in years (ie the same as the reciprocal of the probability of occurrence in any one year). The ordinate represents the return period in years to a log scale; the abscissa the epicentre distance from Hong Kong.

Buildings tremble at M=5, brick buildings are slightly damaged at M=6, large cracks in weak buildings and slight damage to reinforced concrete buildings occurs at M=7. The second figure below shows that only once in a 1,000 years will an earthquake occurring 300 km from Hong Kong have a magnitude M=7 . An earthquake 250 km distant of M=4 occurs once every year and M=5 once every 10 years. The value of M actually experienced in Hong Kong relates to the attenuation effects as the wave travels from the epicentre.



Relative seismic activity rates

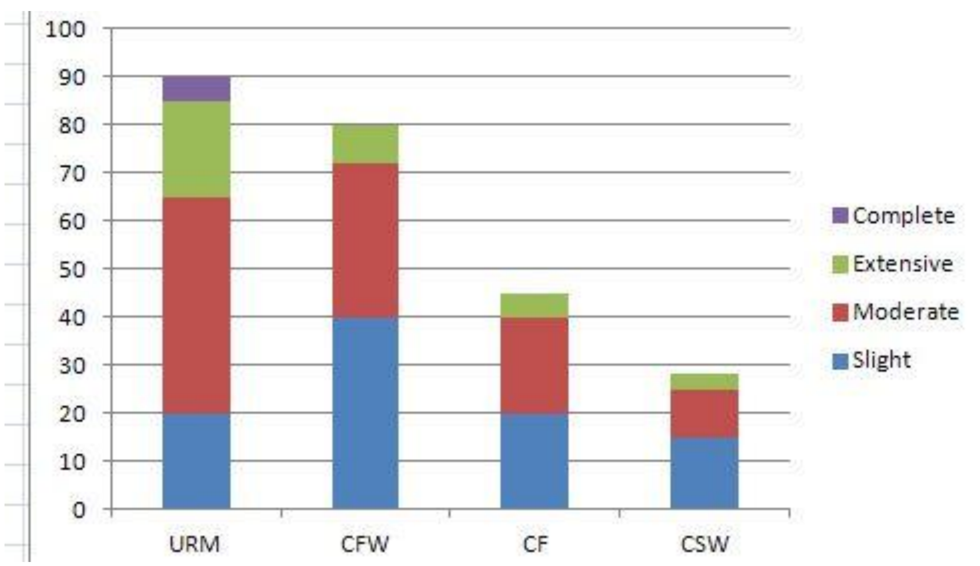


Earthquake return period versus distance from Hong Kong

An extremely thorough detailed study of the vulnerability of Hong Kong's existing building stock was also made. Seismic ground accelerations were imposed of 0.05g (occurs statistically every

72 years in Hong Kong), 0.15g (475 years) and 0.35 g (2475 years). Costs of territory wide damage repair were also estimated. The accelerations were chosen to conform to the widely used US earthquake performance codes, and approximately represent probabilities for Hong Kong of an earthquake occurrence in a 50 year building life, of 50%, 10% and 2% respectively.

It was concluded that the older unreinforced (URM) masonry buildings would have a 20% likelihood of slight to moderate damage following a 72 year event and concrete frame buildings with infilled masonry (CFIW), also now quite old, of about 10%. The more modern concrete frame (CF) and shear wall designs (CSW) would hardly be affected. All types of structure would suffer slight to moderate damage under the 475 return year assumption, about 15% of the CFs and 10% of the CSWs . For the 2475 year assumption virtually all URMs across Hong Kong would be affected, about one third of them suffering extensive damage up to total collapse. Even at that level of ground acceleration, however, rated as 'extremely unlikely', over half of the more modern and numerous CFs and CSWs would remain undamaged, although conversely, nearly half of the CFs would suffer slight to moderate damage as would about 30% of the CSWs. As for risk to life, it is interesting that even for this extremely unlikely case the probability of a URM occupant (the most at risk) losing his life in any year is less than 'one in a million', or 0.0001%. The histogram below gives the estimated damage assessment for most of the present building stock for the 2475 year return earthquake.



% Degrees of Damage to Four Types of Building Stock—The 2475 year return event

The GEO, of course, has made a slope risk assessment in relation to earthquakes. The writer understands (personal communication from government source) that the "probability of natural terrain landslides triggered directly by seismic activity is about one order of magnitude lower than that of rain-induced landslides”.

Earthquake Risk Mitigating Action

Building design measures are already successful in preventing disasters due to very strong winds.

As for earthquake mitigating action, although Hong Kong buildings have so far barely suffered, the study now out to consultation, confirms that many countries with a similar moderate risk classification to Hong Kong’s , do insist on strengthening buildings against earthquakes.

The Ove Arup consultation report also shows that the introduction of seismic design rules for all new buildings in Hong Kong would produce a positive cost benefit, treated statistically. The extra strengthening costs are estimated at less than 0.1% of total building costs, which is 8 to 10 times less than the probabilistic costs of repairs due to earthquake damage for concrete buildings of the types built today. Compensation costs associated with injuries and deaths, incidentally, were found to be very small by comparison with damage.

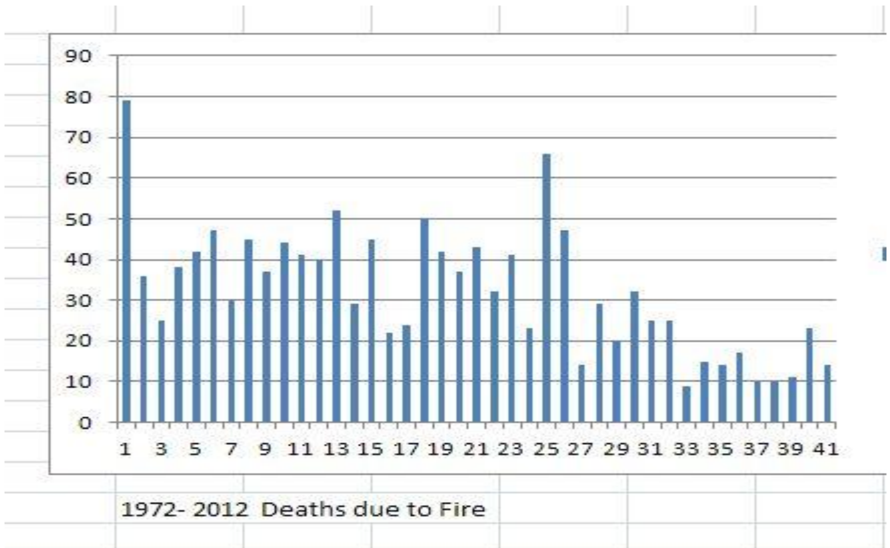
The report also finds that the cost of upgrading existing buildings is not worthwhile as such costs are much greater than only the 0.1% extra for buildings designed for earthquake resistance ab initio. A relevant factor also, is that most of the risk is associated with the older masonry and concrete frame masonry infill structures, the majority of which will probably be demolished during the next decade.

5. Protection against Fire Disasters

Scale and Nature of the Fire Threat Problem

Deaths in Hong Kong due to fire have numbered 1,325 since 1970, an average of 30 per annum. Disastrous fires, such as the 1996 Garley Building fire with its 41 deaths, do not occur very often. A more typical year has averaged about 12 deaths since 2003 spread across a very large number of fire incidents, of which about 11 per annum have been classified as major fires. These figures relate to a population of 7 million. The probability, therefore, of death by fire in any one year for an individual citizen today is of the order of 0.0002%. This is higher than for weather related deaths but is essentially of the same order of magnitude. (see the first two figures in this paper above).

The histogram immediately below (derived from FSD supplied data) shows the pattern over the years. A reduction in annual deaths over the last 15 years or so is evident.



The deaths are in blue (darker) and the major fires in Green (lighter). The average number of deaths per year for each of the last four decades, derived from the same figures, is shown in the table below. The reduction in the last decade is very clear.

1973-1982	1983-1992	1993-2002	2003-2012
38.5	38.4	32.9	12.5

The nature of the threat is influenced by the built environment characteristics and the population density. Hong Kong is one of the most crowded cities on earth, the people generally living in multi-storey buildings in small and often crowded flats. As the decades go by these buildings are getting ever taller. There are now many super-tall buildings in Hong Kong for instance (defined as higher than 300 metres by the Council for Tall Buildings and Urban Habitat (2011)).

Hong Kong's underground mass transit railway system is often jammed full. The possible consequences of an outbreak of fire on these trains, tunnels or stations could present an enormous challenge to the city's Fire Services Department. Increasing also, is the construction of large shopping malls with large areas of open spaces. Fires are much more likely to get out of control in large open areas containing combustible materials and pedestrian escape routes are generally much longer than those for traditional low to medium rise buildings in Hong Kong.

The threat today is actually increasing because we do not fully understand how to predict the spread of fire and smoke in many modern buildings and we do not know how to model the behaviour of people escaping a fire in such buildings. Shopping mall spaces, for example, are large, the numbers trying to escape possibly huge, and the escape routes are unfamiliar to the escapees. Traditional fire safety design features and building code rules assume fires arise in relatively small spaces, or compartments, and control the maximum distances to escape staircases and the minimum widths of corridors and staircases. These dimensions vary somewhat in relation to the expected numbers of escaping people. But for office and residential buildings above 30 storeys, say, although the number of escapees is predictable, the escape staircases at lower levels would have to be very wide indeed to enable a fast flow of people, so wide that much of the building area floor plans would have to be given over to escape provision. In fact, economic arguments prevail and this sort of escape space is not provided. The only partial, and unsatisfactory, compromise which seems to exist is to limit the numbers of people who work and live at high levels, usually by providing high standard spacious accommodation.

Two consequences which have arisen from this situation are that:

(1) The Buildings Department and the Fire Services Department are necessarily pro-active in reviewing and updating the rules guiding building designers and the fire fighting and warning systems to be installed (see below). The authorities (since 1998), have also allowed a 'fire engineering approach' to be adopted as an alternative to conforming to prescribed rules. This allows an architect freedom to design his building as he wishes as long as he can demonstrate, through fire engineering analyses of his proposal, that his design meets the safety standards expected of a building conforming to the prescriptive design rules. This is easier said than done and it is equally difficult for the approving authorities to know whether the condition is achieved or not.

(2) Some necessary research is taking place (see below) , including that by the Fire Engineering Research Centre in HKPU (the Hong Kong Polytechnic University) in an effort to understand much more about the spread of fire and smoke under various space and ventilation and available fuel conditions and how to model that behaviour for practical predictive design purposes.

The above commentary has related only to building characteristics. The fire threat to life is just as importantly affected by the compromises between economics and safety which society collectively makes. <u>Guaranteed</u> safety against any risk, including fire, can come only at an unacceptably high price in money and personal freedom terms. The required safety rules in the building code, which have gradually evolved over a long time, represent the compromise that society has come to accept. After all, fire safety rules impose restrictions limiting the building owner's freedom to create the best possible building, from both the economic and usability points of view. A fire may never break out and yet the geometry of the building is for ever limited by the rules. Society makes trade offs between risk to life, costs and building use for purpose.

The building user likewise is not free to install whatever he likes in a building, eg. to store materials wherever he likes and as much as he likes and as flammable as he likes. The simple storage of materials, including stock in the case of traders and shopkeepers, in corridors and on staircases can block off an escape route. Thus, the reality, in practice, is the need for constant vigilance by the Fire Authorities, to guard against the populace breaking the rules in all those respects.

Changing the uses of buildings and modifying building structures and the materials of construction without authority clearance as the years go by is also prevalent .The authorities can only hope to catch a small proportion of these offences, so widespread are they. The threat of fire in general is increased by such indiscipline.

Government Four Pronged Strategy to Minimize Risks

The Hong Kong Government continually keeps legislation under review as stated above. Legislation applies to quantities and storage of combustible materials, building design parameters, warning of an outbreak of fire to building occupants, ready to hand equipment enabling a small fire to be put out quickly and the signposting of escape routes. Below is a brief outline of the fire legislation development history in Hong Kong and the responsibilities of the Buildings Department and the Fire Services Department, as set out in detail under the Buildings Ordinance and the Fire Services Ordinance (references given below)

The following four pronged government strategy exists to minimize loss of life and property damage due to fire.

a) Passive Construction Control

Buildings must be designed so that fire outbreaks can be confined easily and walls and doors so constructed that fires can be confined for given minimum periods of time. The design of all new buildings must meet the required standards before construction can commence. The same applies should there be any subsequent building alterations. Buildings must also meet ease of escape criteria.

Building plans, as stated above, are assessed either against prescriptive criteria laid down by law, or else, since 1998, via the fire engineering approach. The latter involves scrutiny of the expected performance of the intended building on its individual merits, based on detailed engineering analysis of the behaviour of fires which might arise and of the escape patterns.

In support of the prescriptive passive approach, legislation lays down the maximum sizes of open spaces in buildings, the 'fire ratings' of walls and doors expressed as the number of hours they are able to contain the 'design fire' before breaking down, and escape route minimum dimensions. Escape criteria are expressed in terms of maximum distances to fireproofed escape staircases and minimum widths for those corridors and staircases.(see Table below for some figures used in Hong Kong)
The passive approach also applies to the potential of the combustible materials within a building to create and sustain fires. Laws exist to minimize the use of flammable materials in furniture, say, and there are strict rules relating to the storage, handling and allowable quantities of dangerous materials.

<u>Fire Resistance Period.</u> Domestic, hotel rooms Industrial buildings All basements	 1 hour 2 4	
<u>Compartment Max Size</u> Above ground Below ground	 28,000 cubic metres 7,000	
<u>Escape Routes</u> Occupant numbers	 <u>301-500 people</u> 2 exit doors Minimum total width 3.0m <u>1001-1250 people</u> 5 exit doors Minimum total width 7.5m	 No door/route <1050 mm. No door/route <1350mm

<u>Examples of prescriptive rules in Hong Kong related to passive control</u>

In the vast majority of cases, building designs follow the prescriptive rules laid down. As indicated above, however, it is very difficult to be sure, in the case of many modern buildings, what those required prescriptions really should be. For instance, refuge floors are provided in very tall buildings. Refuge floors were of no help in the New York 9/11 disaster, but even if that were an unusually massive event, it is not certain how refuge floors would fare in a more conventional but major fire and nor can we predict the extent to which individual escapees would put their trust in them.

In only about 300 cases in Hong Kong so far, have developers taken the fire engineering approach. Taking this route it is possible in theory, to produce a building which is both safer against fire and cheaper. The danger , however, is that the quest for a cheaper building takes precedence and the supposedly justifying fire engineering analyses might not really be rigorous enough and may involve too much qualitative judgment. The approval authorities, who must assess these judgments, are not usually in a position to do so, in any certain objective manner. But rather than to disallow new types of buildings, society prefers to take bigger risks in the matter of fire safety. The approval authorities often accept the qualitative judgments made by designers taking the 'fire engineering approach' because of the lack of rigorous countervailing arguments.

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As stated above, the need is clearly urgent for the research community to develop accurate predictive modelling of the spread of smoke and fire for various conditions of ventilation and combustibles heat release rates . Very large scale experimental test burning facilities, of which very few exist anywhere, are essential for validating proposed models and this is a noticeable lack for Hong Kong.

b) Active Control

The second prong to the strategy is an active approach, by which every effort is made to give warning on site of a fire outbreak and for the people on the spot to extinguish the fire before it gets out of control and needs the attention of the professional fire fighting services. Warning systems are the first essential. These consist of smoke detection alarms, heat detection alarms and others. The next essentials are sprinkler systems automatically set off by heat, water curtains and mist flooding systems. The usual hand operated fire extinguishers must also be provided and sand buckets. Fire hydrants and hose reels (for use by occupants) are also provided for all buildings. Fire hydrants are to be used only by the fire fighting emergency services once they have arrived on site.

c) Fire Safety Management

Most buildings in Hong Kong possess a Property Management team which is indirectly responsible for the fire safety of the communal areas of the building amongst its several other functions. 'Indirectly', because although a Code of Practice exists requiring the team to maintain the passive and active fire provisions, such as preventing the blockage of escape routes there seems not to be legal force behind it. When the Fire Services Department requires remedial action following an unsatisfactory inspection (see below), the enforcement order is served on the owners and not the Property Manager. Property Managers are not normally trained in fire engineering principles and the associated technicalities and this situation can be seen as a weak link in the fire safety control system. In fact the recognition of day to day Fire Safety Management as an important link is relatively recent (1998) and the situation is likely to be slowly tightened up. Fire Safety Engineering courses are now taught in Hong Kong at undergraduate and postgraduate levels.

d) <u>Professional fire fighting, rescue and ambulance services</u>

If all else fails, lives are saved and injuries reduced by the rapid deployment of professional fire fighting, rescue and ambulance services.

High priority is given by the Hong Kong government to a generous provision of these services as a conscious component of the total strategy. 10 minutes, for example, is the maximum time intended for a fire to be reached anywhere in Hong Kong. The force is highly trained.

Also extremely important is the use of this force for never ending ongoing inspections of premises. Continued monitoring uncovers many failures to carry out the fire protection laws, from blocked exits , to inadequate provision of fire detectors, extinguishers and dangerous concentrations of combustible materials, etc. Legally binding enforcement orders follow such derelictions, served on the building owners as stated above.

Fire Authorities in Hong Kong and Legislation

The Buildings Department (BD) and the Fire Services Department (FSD) constitute the Fire Authority in Hong Kong.

The former is responsible for all aspects of the building geometry, types of spaces and the construction materials used and wall and door fire rating thicknesses – ie the passive control aspects above. The FSD, for the fire fighting installations and warning systems in buildings- the active control aspects above. The FSD also trains the emergency teams and deploys them on demand, and runs the regular building inspection programmes.

The fire protection legislation is based on the legislation common in the UK. This was satisfactory for the hundred years when buildings were low rise and not dissimilar in character to buildings in the UK, at least as far as fire dangers were concerned. Multi-storey residential buildings mushroomed in Hong Kong, however, about 40 years ago, not typical of the UK, as well as multi storey commercial buildings. Factories and schools were not high rise but commonly comprised 3-5 storeys. In the UK such buildings remained predominantly of one storey. Hong Kong fire codes had to change to reflect these new forms in the ensuing decades.

After a bank fire in 1994, which took 13 lives and the 1996 Garley Building disaster, a major review of all regulations was undertaken, and for the first time, attention was also given to the upgrading of existing buildings. While this process was going on Hong Kong reverted to Chinese sovereignty in 1997 and the review also incorporated study of the fire regulations which existed in China.

The upshot is that most existing commercial buildings were required to upgrade their active control systems , there was much tightening of the rules for new buildings (eg the provision of refuge floors) , the 'fire engineering approach' was allowed as an alternative to the prescriptive approach to design and the concept of proactive fire safety management by property managers was added to passive controls and active controls as the third component of the government's overall fire risk mitigation strategy.

Although the 'fire engineering approach' is far from ideal in practice because of our present unsatisfactory understanding of the fire dynamics within many modern buildings in Hong Kong, it is nevertheless philosophically sounder than the prescriptive approach for the modern super-tall buildings and shopping malls. Rather than to hold back progress in building development the FEA approach treats each design on its merits in relation to the passive and active fire controls to be applied to that design. Once the ability is achieved to realistically simulate fire and smoke behaviour and the escape behaviour of personnel the FEA approach will be entirely appropriate. In the meantime, assumptions based on common sense are made by building designers and approval authorities on likely behaviours, assumptions not yet evidentially based, lacking both scientific underpinning and actual experience of any major fire in a modern large building.

Relevant Research taking place in Hong Kong

Slope Stability

Optical fibre Bragg grating (FBG) sensors are currently being experimented with for slope monitoring applications. Such sensors are of high resolution, are more reliable long term, can be more compact and are not affected by electromagnetic radiation (this latter, is relevant to assessing strains in the reinforcing bar of a soil nail). A broadband light source input to the optical cable of the gauge is converted by a Bragg grating to a particular output wavelength, the value of which changes as the cable refractive index is altered by force and temperature induced changes in the initial gauge length. FBG based inclinometers are currently being field trialled in China with the help of Chinese academics (Pei et al 2012). FBG slope movement and soil nail strain gauges have been successfully trialled on a roadside slope in Hong Kong by HKPU and Nanjing U in collaboration with the GEO and Ove Arup (Zhu et al, 2012) .

Satellite based image processing technology has recently reached the stage where ground movements can be detected at centimetre level accuracy in real time (mm accuracy if comparisons at 24 hour intervals are acceptable). Professor Ding at HKPU is the first anywhere to have achieved this degree of accuracy using only satellite images. He has built upon interferometric synthetic aperture radar technology (InSAR) in producing the TCP-InSAR (temporarily coherent point) method of comparing successive satellite images of the same piece of ground. Retrospectively, Ding's method was applied to successive images of the ground as it existed prior to the Zhouqu landslip in China, which killed 2,000 people. Significant ground movements were revealed by the method, movements probably sufficient to have led to timely evacuation, had such TCP-InSAR based monitoring been available. (Zhang et al, 2010)

Research into the behaviour of soil nails under stress is also conducted at HKPU since little fundamental work has been done to thoroughly understand the mechanisms of failure of this slope reinforcing technique. The frictional strength of the interface between the grout of the nail and the surrounding earth is critical to the nail's ability to react against slope failure. One practical finding of the research team is that there is a sufficiently big gain in such frictional strength to justify the use of high pressures when applying grout during soil nail construction. (Yin et al, 2009).

Flooding

There seems to be little fundamental research relevant to floods and flood control taking place currently in Hong Kong. Water level simulation modelling has been developed (Li and Song (2006)) to provide predictions of sea level heights allowing for surges and maximum wave heights, the results comparing very well with actual recordings of typhoon events. The Hong Kong Observatory maintains a permanent watch on sea levels and storm surges. A lecture (Lee et al, 2010) delivered in Hong Kong concluded that a "pessimistic, but not unrealistic estimate of sea level rise---even ordinary spring tides--- would be sufficient to bring sea flooding to low lying areas –with or without typhoons" .

The recent research based on satellite technology and very accurate image analysis, with mm level positioning accuracy in three dimensions, using the TCP-InSAR technology (above) developed in Hong Kong (Ding et al 2011) was also employed to assess flooding risks in Hong Kong allowing for topography, installed drainage capacity, long term sea level rise and typhoon effects on sea level. If sea levels become 0.8 metres higher than they are now there will be inundations unless sea walls have been already raised, but a rise of up to 0.4 metres need not cause undue concern. His imaging also shows, curiously, that the sea wall at the New Praya location in Kennedy Town is lower than the sea wall levels generally provided.

Wind and Earthquake

It has been argued in Hong Kong that our designs are already earthquake resistant because very high wind loads are catered for. The nature of seismic loading, however, is quite different to that of wind loading. Seismic loading consists of a violent shaking of the foundation. Xu et al recognised that typical Hong Kong column designs contained much longitudinal steel in order to resist high wind bending but the ability of those columns to cope with earthquake induced shearing forces, as they usually possess only nominal quantities of 'link' steel, was relatively weak. The columns in Hong Kong need to be more ductile in the face of strong shearing actions. Laboratory tests substantiated the point. (Xu et al, 2003)

Also identified was the potential weakness of the 'transfer plate' design, typical of many high rise buildings in Hong Kong. Usually the building superstructure sits on top of a very strong floor system of concrete beams and slabs. This 'transfer plate' sits atop the basement and shopping malls substructure. Earthquake resistant designs elsewhere in the world generally adopt the "strong column-weak beam" philosophy. At the level of the transfer plate, however, the situation is one of weak column – strong beam. The structural frame below the transfer plate was thought to be particularly vulnerable. 1-20 scale shaking table experiments were conducted to simulate earthquake loading on a 34 storey building (Li at al 2006). There were 3 levels underneath the transfer plate. For a moderate M=7 earthquake, as was experienced in 1918, the structure remained undamaged below the transfer plate and moderately damaged (sufficient to need subsequent repair) with some cracking in the storeys above especially that floor immediately above the transfer plate. On simulating the extreme earthquake design condition (ie a 2% probability of the earthquake occurring at some time during a 50 year building life), the structural integrity was destroyed at the level immediately above the transfer plate to the extent of collapse.

The Ove Arup report (2007) above, reported non linear dynamic computer analyses of transfer plate structures which found that the frame below the transfer plate behaved well even under the extreme earthquake condition. The upper structure suffered to a greater extent than the lower. These results are in general agreement with the experimental result of Li et al.

Fire related

It has been made very clear above that our ability to accurately model and predict the behaviour of a fire in any particular case is limited, as is our ability to model the behaviour of a mass of people escaping a fire. Particularly because of the very tall buildings and large enclosed spaces such as shopping malls and atria, and crowded underground railway systems it seems, to the authors, that a very large research effort is urgent to enable accurate predictions to be made with gradually increasing levels of confidence as the research proceeds over time.

In fact very little effort is applied to this problem. There are many more researchers, for example, concerned with improving air conditioning systems, to select a topic at random. This may be important but it is not related to the saving of lives.

University based research does exist in Hong Kong (HKPU and CityU). Nevertheless, there are only about 6 academics in total in both places in the fire research business supported by their few assistants and Ph.D students. Even at that, these researchers in Hong Kong form the largest group amongst the few universities all over the world involved in fire engineering research. Such facts really brings home the paucity of fire research effort in universities. Some major countries do have significant government owned fire research establishments, but there are less than 10 of these worldwide.

Research taking place in Hon Kong to advance our understanding includes the following topics.

1) The heat release rates of combustible materials and the relationships between mass of combustible materials and energy releases and energy transfer across distances. There is evidence , for example, that the 'design fire' assumptions generally used around the world are unsafe and underestimates of what can happen.
2) The physics and chemistry involved in flame production and its spread, in smoke production and its spread, how ventilation paths arise and the effects of building shapes and openings sizes and locations on ventilation patterns and smoke dispersal.
3) Simulation modelling of fire and smoke spread in the light of 2) above and its validation in very large scale experiments. There are encouraging signs that smoke modelling is becoming more reliable, less so with the spread of fire itself.
4) Simulation modelling of the mass movements of people in a desperate hurry to escape fire and smoke. Understanding of human psychology and the variability to be expected in likely behavioural responses is needed to provide the essential underpinning to such simulations. It is not to be supposed, for example, that the existing models simulating the exiting of passengers from underground railway stations in the routine orderly fashion of the normal day are of much relevance to a fire breakout.

The equipment required by fire researchers includes high power computing for CFD simulation modelling, very large scale/full scale burning test facilities and laboratory scale chambers where variables can be individually controlled. Hong Kong possesses no large scale burning test facilities. There are several in Mainland China, however, which are utilized by the Hong Kong academics at some significant level of inconvenience and reduced productivity. This city of 7 million people, given the fire safety uncertainties of its modern buildings should surely have such facilities of its own.

6. Disaster and Emergency Management

In addition to the Daya Bay Contingency Plan for a nuclear accident mentioned above, the Hong Kong Government has contingency plans in the event of natural disasters and of severe weather conditions (Security Bureau Circular 2009). These relate to the landslides and flooding sections of the paper above and cover all conceivable government departments including the Fire Services Department, for example. The FSD has skilled rescue and ambulance teams deployable in any kind of emergency, not only for fires.

Based on this, those government departments responsible for building and civil engineering work are prepared for natural disaster emergencies under the guidance of a Development Bureau Technical Circular. (Development Bureau 2011)

The response to an emergency is by a team appropriate to the nature of the emergency. The principle is that as few departments as possible are to be involved, communications are limited to those departments only and maximum delegated authority is given to those at the scene of the incident. The government secretariat only becomes involved if the incident is of greater significance as decided by the police and fire services. If the incident is a major one with wider threats to life and property only then is an Emergency Monitoring and Support Centre activated.

The philosophy is one of maximum speed of response and a minimum of potentially obstructing crossed lines of authority and red tape.

This ‘emergency’ phase is followed by a ‘rescue’ phase, then a ‘recovery’ stage to help the victims and finally a ‘restoration ‘phase.

The construction industry is called upon at the restoration stage. The technical circular above states that relevant departments are required to make provision for rapidly mobilizing the plant, materials, labour and skilled personnel needed to deal with incidents. It seems that ‘term contracts’ exist anyway, to deal with hazards which might appear from time to time and these contracts include clauses requiring rapid mobilization on demand.

Hong Kong operates systems warning of impending heavy weather. Warnings are broadcast on radio and television and websites in respect of Tropical Cyclones, Strong Monsoons, Heavy Rainstorms, Thunderstorms and Tsunamis. There are also Landslip, Flooding and Hill Fire warnings. All broadcast warnings come with advice.

Some types of warning are given a rating and advice comes with each rating. For instance there are five different tropical cyclone ratings. A No.8 Signal, for example, warns of gale force winds and that everyone should stay in a safe place with locked doors and windows.

Rainstorm warnings come in three colours. The intermediate RED rainstorm warning means an expectation of some flooding and traffic congestion. Children are not to go to school but if already there, must remain there, until the warning is lifted.

7. Concluding remarks

Loss of life and economic harm in Hong Kong has been mainly due to heavy rain induced landslides and floods and to fires in buildings. Hong Kong is fortunate in that it has never suffered a truly major disaster such as other countries do, from earthquakes and tsunamis and even nuclear accidents. Nevertheless serious losses to landslides, floods and fires have occurred.

The long term slope inspections and strengthening programmes originated after the 1972 landslide deaths, through the newly created Geotechnical Control Office (now Geotechnical Engineering Office) may well mean that such a big disaster will not occur again. At least 20 years have elapsed since there were more than 10 deaths in any year due to slope failures.

Likewise, the establishment in 1989 of the Drainage Services Department and the resulting 25 years of steady investment in major storm-water removal schemes has reduced the number of ‘flooding black-spots’ by over 75 % since the early 1990s.

It is very likely that the modern systems of warning and emergency actions taken by the authorities have also been important to the reductions in deaths from landslides and flooding. The technical measures are not likely to be solely responsible for the improvement.

As for deaths from fire, in spite of the greater and worryingly (to these authors at least) unquantifiable risk levels associated with some of our modern buildings, the combination of passive control measures, active measures including warning devices and on the spot fire fighting equipment and generous investment in fire fighting resources, seems to have lowered the annual number of deaths noticeably in the last 10 years. This might be supposed only a relatively short period and it is perhaps too soon to infer any significance. Nevertheless, a major fire has not yet occurred in one of our very tall buildings or a shopping mall. Statistically there will be one at some time unknown and a disaster of major proportions is possible. It has to be admitted there is no evidence that this pessimistic view will be borne out in the event but neither is there evidence to the contrary and a research push seems to be essential and the need for it obvious. Society, nevertheless, has given its consent to living with this level of uncertainty. The superior economic performance of the new buildings over the old trumps fire safety uncertainties.

It is interesting to note that society, nevertheless, is quite willing to pay handsomely to save lives and minimise damage in the case of flooding. The DSD's flood prevention strategy to reduce inconvenience and economic losses and some deaths has resulted in the construction of huge DSD drainage tunnels and underground storage tanks, for example, which will be empty for much of the time. They will only have to do the full job they are designed for once every two hundred years statistically. Landslides prevention is more important to the saving of lives than flooding in numerical terms but only the 10 year storm is catered for in the former case rather than the 200. This apparent inconsistency is due to the realities of soil mechanics whereby it is not possible to maintain the FOS of 1.4 against the 200 year rainstorm with the strengthening techniques in common use. An FOS greater than 1.0 should still be present, however, and slope failure remains unlikely even in a 200 year storm for properly strengthened manmade slopes. Society draws the line at the costs of achieving a slope stability FOS of 1.4 in a 200 year rainstorm.

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A Note on Sources of Information

Sources of information are often, but not always, given at the relevant point in the text.

The data on fatalities were provided directly, in answer to our requests, by the Fire Services Department and the Geotechnical Engineering Office of the Civil Engineering and Development Department in relation to deaths by fire and by landslides. The Drainage Services Department does not appear to maintain statistics on deaths due to flooding. The Hong Kong Observatory has much data on the consequences of weather related events in various forms, including detailed reports on tropical cyclones for example. Although there is much data on fatalities in the public domain it seems not to be consolidated anywhere.

The photographs in Section 3 on Flooding Mitigation were copied from the DSD website 'Flood Prevention' above and those to do with the Lai Chi Kok transfer scheme, from the DSD website Technical Manuals above

The two graphs in Section 4 concerning earthquake risk in Hong Kong were taken from the 2006 Ove Arup Report above.