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A review of landslide problem and mitigation measures in Chongqing (重庆) and Hong Kong (香港) Similarities and differences

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Abstract

The cities of Chongqing and Hong Kong are both located at hilly areas which are highly populated, with buildings and major highways located very close to slopes and earth-retaining structures. Landslides and rockfalls are very common in both cities, and large expenditures are being incurred by both Governments on the investigation, design and implementation of mitigation and preventive measures to reduce the likelihood of the loss of life and economic losses due to landslides.

As a result of the collaborative studies and technical exchange programs between the University of Hong Kong and the Chongqing Jianzhu University (重庆建筑大学), a more in-depth understanding of the landslide problem, methodology and mitigation measures in Chongqing and Hong Kong was achieved. The objective of this paper is therefore to: (1) highlight the similarities and differences of the slope safety problems which these cities have been facing and (2) present and compare the key technical approaches these two cities have been undertaken to reduce the risk of landslide and rockfalls, so that both cities could benefit from the experience and lesson learnt.

Based on the review of literature and published case records, it is concluded that the city of Chongqing has to deal with natural hazards such as earthquake, river erosion and flooding more than that in Hong Kong, but both cities have been applying practical and latest technology to mitigating the landslide problem.

It is recommended that the city of Chongqing should consider establishing a sustainable long-term landslide management plan and that the landslide prevention system being used in Hong Kong could be a good reference starting point.

Keywords: Landslides; Natural hazard; Risk, mitigation measures; Monitoring; Management plan; Chongqing; Hong Kong

1. Introduction

The cities of Chongqing and Hong Kong are both located at hilly areas that are highly populated, with buildings and major highways located very close to slopes and earth-retaining structures. Landslides and

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rockfalls are very common in both cities, and large expenditures are being incurred by both Governments on the investigation, design and implementation of mitigation and preventive measures to reduce the likelihood of the loss of life and economic losses due to landslides.

For example, Chongqing was listed the top 1 among 70 cities in China in the National Planning Scheme between 1999 and 2000 (Shu and Hu, 1998) where the reduction of hazard due to landslides and implementation of mitigation measures had been given the highest priority among other natural disaster hazards.

Similarly, since 1976, the Government of the Hong Kong Special Administrative Region (HKSAR) has spent over HK$3.6 billion on studies and upgrading works on both public and private man-made slopes and retaining walls which were formed before the Geotechnical Engineering Office (GEO) was established and which could pose a risk to life or property (HKSAR Internet webpage: www.info.gov.hk). These studies and upgrading works are being carried out under a long-term Landslip Preventive Measures (LPM) Programme where the long-term strategy is to complete the upgrading works for another 2500 substandard Government slopes and to complete the detailed studies for another 3000 private slopes by the year 2010.

The Jockey Club Research and Information Centre for Landslip Prevention and Land Development was established in October 1998 in the Department of Civil Engineering of the University of Hong Kong. The Jockey Club Research and Information Centre has jointly carried out a number of slope safety research projects with some Mainland China's prominent universities through a collaborative research program and one of the on-going topics is on the application of soil nailing technology to stabilization of unstable slopes in

Fig. 1. Geographical location of Chongqing and Hong Kong.

Chongqing. As a result of the collaborative studies and technical exchange programs among these universities viz. the Chongqing Jianzhu University (重庆建筑大学), a more in-depth understanding of the landslide problem, methodology and mitigation measures in Chongqing and Hong Kong was achieved. The objective of this paper is therefore to: (1) highlight the similarities and differences of the slope safety problems which these cities have been facing and (2) present and compare the key technical approaches these two cities have been undertaken to reduce the risk of landslides and rockfalls, so that both cities could benefit from the experience and lesson learnt.

2. Factors causing landslides

The city of Chongqing is located at the Sichuan Province (四川省), whereas Hong Kong is located at the southeast coast of China. Fig. 1 presents the geographical location of these two cities.

The population in Chongqing is about 30 million, whereas in Hong Kong, it is only about 7 million. The city of Chongqing covers an area of about 820,000 km^2, whereas in Hong Kong, it is about 1100 km^2, very much smaller than Chongqing. In terms of the risk of life and economic losses as a consequence of slope failure, the major factor to be considered in any slope study and mitigation measures is the proximity of the slope or earth-retaining structures to populated areas, traffic and building. The landform in Chongqing and Hong Kong is hilly with occupied buildings constructed very close to slopes or on elevated platforms supported by earth-retaining structures. Fig. 2 shows that it is common to have residential buildings constructed at steep slopes and highway located very close to slopes in both cities, because of the scarcity of flat land. A comparison of the percentage of land at different groups of slope angles is presented on Fig. 3. Based on the local experience, the slope at Chongqing is generally stable when the slope angle is less than 20° or greater than 50° (Shu and Hu, 1998). A similar observation can also be found for the slope in Hong Kong. The same observation is consistent to the fact that for a slope which has an angle greater than 50°, it is most likely that it is a rock slope with failure occurrence much less than of a soil slope due to the higher shear strength of the rock mass (Fig. 3 in Hu, 1995).

Fig. 3 indicates the fact that for more than 50% of the available land in Chongqing and Hong Kong, it is on sloping ground where the slope angles range from 20° to 50°, a condition which is most vulnerable to stability problem.

Factors affecting failure of slopes have been described by Kuang (1995) and 张梁 (1998) for Chongqing and Wong et al. (1998) for Hong Kong. A range of triggering and contributory factors leading to the

Fig. 2. Landslide in Chongqing and Hong Kong.

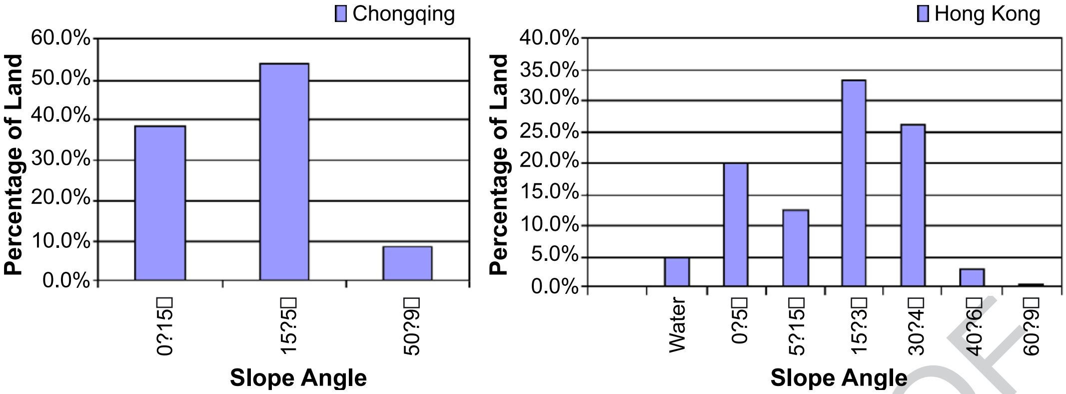


Fig. 3. Percentage of land.

event of a landslide could be broadly classified in Table 1.

An examination of Table 1 suggests that the slopes in Chongqing have to face natural hazards (earthquake and river erosion/flooding) more than that of Hong Kong. River erosion would undermine the toe of the slope, reducing the restoring moment of the sliding mass, whereas flooding would decrease the effective stresses in the slip surfaces particularly when the pore pressures in the saturated sliding mass are not dissipated quick enough. Shu and Hu (1998) indicated that the river level in Chongqing could fluctuate by 5 m daily and 30 m annually and could account for about 40% of the landslide cases.

Table 1
Summary of landslide triggering and contributory factors for both cities

Landslide triggering factors	Chongqing	Hong Kong
Rain, rise in groundwater level, etc.	✓	✓
Adverse construction/human activities	✓	✓
Deterioration and erosion of surface	✓	✓
Bursting and leakage of buried water services	✓	✓
Earthquake	✓	
River erosion and flooding	✓	
Contributory factors		
Adverse geological conditions	✓	✓
Inadequate design	✓	✓
Poor construction	✓	✓
Adverse topography	✓	✓
Inadequate maintenance	✓	✓

3. Rainfall intensity

Rainfall is one of the main factors contributing to landslides in Chongqing and Hong Kong. In Chongqing, the average annual rainfall is about 1125 mm, whereas it is about 2225 mm in Hong Kong (about 50% more rain than Chongqing).

Based on the work of Li (1995), the following guidelines are established for providing early landslide warning to the city of Chongqing:

Rainfall intensity	Apparent conditions of slope
≥ 25 mm/day	Show signs of surface erosion
≥ 50 mm/day	Surface erosion intensify
≥ 100 mm/day	Stability deteriorate, marginally stable slope may deform and move
≥ 150 mm/day	Marginally stable slope may deform or collapse
≥ 200 mm/day	Marginally stable slope may deform or collapse Stable slope may also show signs of instability
≥ 250 mm/day	Stable and well vegetated slope may also deform or collapse

Based on the early work of Brand et al. (1984) and recent updating work of Kay (1998), most of the landslides in Hong Kong occurred within 4 h after the peak hourly rainfall and less than 10% of landslides occurred 16 h after the peak hourly rainfall. For a peak hourly rainfall of 70 mm (the Landslip Warning would generally be issued if the 24-h rainfall was expected to exceed 175 mm, or the 60-min rainfall was expected to exceed 70 mm, over a substantial part of the urban area), the probability of having severe landslide (dozens of landslides) is about 15%. For the same peak hourly rainfall, but when the associated 24-h rainfall is less than 100 mm, the probability of having minor incident (none or few landslides) is negligible.

It can be observed from the statistics and experiences gained at Chongqing and Hong Kong that although the annual rainfall in Chongqing is only 50% to that of Hong Kong, landslide would normally occur when the rainfall intensity is greater than 250 mm/day. This threshold level is much smaller than that of Hong Kong and generally indicates that the landslide problem in Chongqing could be more widespread than Hong Kong and more resources should be directed towards minimizing the occurrence and impact of landslides. It is suggested that the peak hourly rainfall intensity in Chongqing should also be considered in the future correlation and observation.

4. Scale of landslides

The volume of landslide material reported in Chongqing is much larger than that in Hong Kong. Fig. 4 summarizes the reported landslide cases in Chongqing, and it can be seen that most of the reported landslides have volume exceeding 100,000 m^3 (张梁, 1998). According to the classification of natural hazards (including debris flow, ground subsidence/cracking, collapse of cavity in karst, etc.) in Chongqing, the following grades are used for prioritization of funding for mitigation works:

Grading	Landslide volume, m^3
Small	< 10,000
Medium	10,000 – 100,000
Large	100,000 – 500,000
Very large	>500,000

In Hong Kong, the following scales are generally used to describe the landslide volume:

Grading	Landslide volume, m^3
Small	< 50
Medium	50 – 500
Large	>500

Based on the record from GEO, the majority of the landslides in Hong Kong have a volume less than 500 m^3. The landslide volume involved in the Fei Tsui Road slope failure was 14,000 m^3, and it was already considered as one of the largest and fast-moving landslides in Hong Kong history (Kwong et al., 1998; Wong et al., 1997).

It could be postulated that many small landslides occurred in Chongqing were either not reported or not recorded into the database, perhaps due to a deficiency in public funding or insufficient awareness from the local residents.

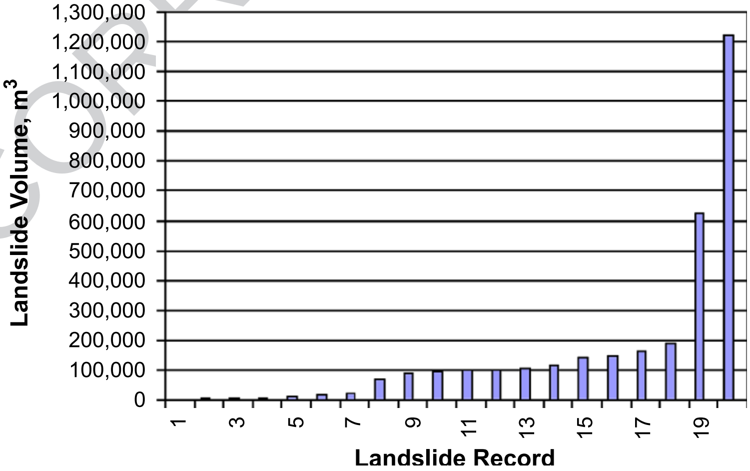


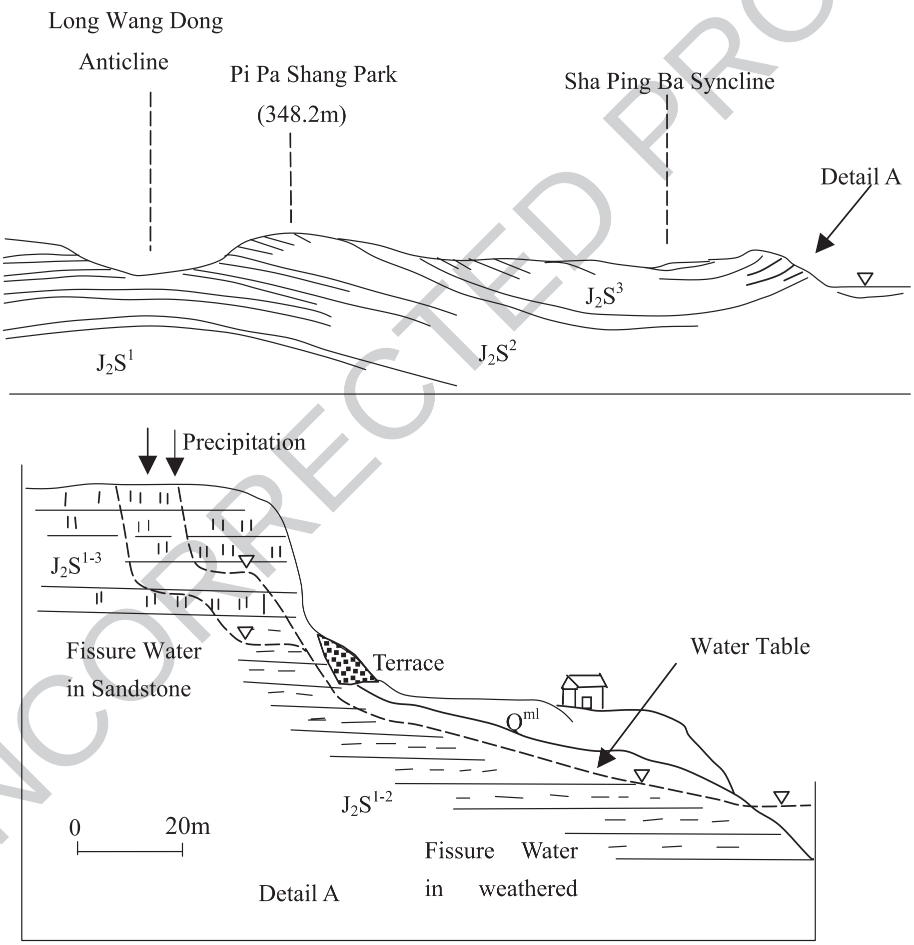
Fig. 4. Landslide volume in Chongqing.

5. Geological conditions

Based on the geological information in Chongqing, the city is underlain by sedimentary rocks of Jurassic Age. The sedimentary rocks are mainly mudstone and sandstone. They are present in the forms of a series of narrow stretching non-symmetric folds. The dip angle of the bedding planes exhibits large variations from gentle to steep and even to vertical within a short distance (Yue et al., 2001). Above the sedimentary rocks are Quaternary deposits and soils including landslide debris, colluvium and alluvium of variable thickness.

The mudstone contains abundant illite and askanite and is therefore sensitive to weathering and would quickly swell (20–110% by volume) and break once in contact with water.

The groundwater table is usually low but could also quickly rise to the ground surface during heavy rainfall in local areas. Local groundwater table usually exists in the fissure of the sandstone and mudstone. Fig. 5 illustrates schematically the complexity of groundwater flow path in sandstone and mudstone. In this figure, due to the interbedded nature of sandstone and mudstone, the groundwater flow path is greatly influenced by the network of joints, faults and other discontinu-



Geological Profile Showing Interbedding of Mudstone and Sandstone

Fig. 5. Schematic view of groundwater effect to slope stability.

ities, which divide the rock mass into an assemblage of closely interlocking blocks. For all practical purposes, the blocks themselves are effectively impermeable. The degree of transmissivity of the rock mass is therefore dependent on the frequency, connectivity and effective aperture of the discontinuities. The effective aperture of the discontinuities is, to a large extent, controlled by the degree of infilling, tectonic history and stress-relief effects of erosion and excavation. The transmissivity of the rock mass can also be affected by the presence of highly fractured zones associated with sub-vertical faulting. It is very difficult

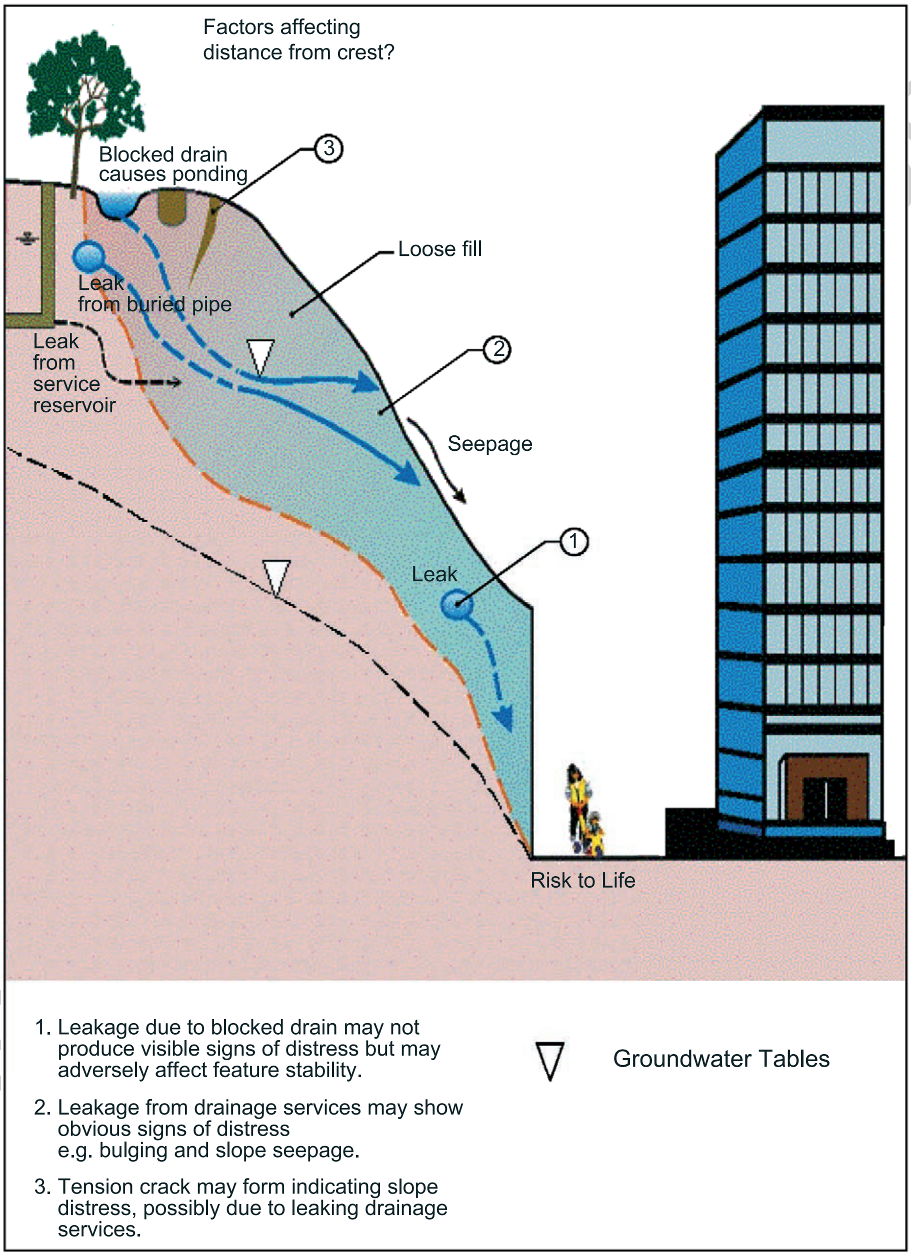


Fig. 6. Contribution of groundwater to slope stability.

to predict with high certainty the phreatic surface for slope stability assessment.

The geology in Hong Kong mainly consists of volcanic and granitic rock of igneous origin of Jurassic Age. Sedimentary rocks, some of which are metamorphosed, cover only a small area. Above the rock formation is Quaternary deposits including colluvium, alluvium, debris flow deposit and marine deposit. Deep weathering of rock is not uncommon and variable decomposition grades, from fresh rock to residual soils, are widely used in Hong Kong (GEO, 1984).

The groundwater table in Hong Kong is quite variable within a short distance and very much influenced by the storage capacity of the soil, infiltration of rain, runoff and subsurface flow. Perched water table, sometimes transient in nature, may exist in the residual soil governing the local stability of a slope.

Groundwater movement takes place from areas of high total pressure head to areas of low total pressure head. Fig. 6 shows that this movement will generally occur along preferential flow paths where permeability values are high and the resistance to movement is therefore less. Potential zones of high permeability include the layers of sand, gravel and cobbles within the alluvium, internal piping in the completely decomposed materials and highly fractured, open jointed zones within the rock mass. The assessment of groundwater table in the urban area could become very complicated if ponding or leakage of water in buried services is present.

6. Mechanisms of landslides

Five major landslides in the city of Chongqing have been described in details by Rao et al. (1995), whereas six landslide case histories along a national expressway in Chongqing have been documented by (Yue et al., 2001). The following summarises the movement history and mechanisms described by Rao et al. (1995). Interested readers should refer to the geological cross sections presented in their paper.

(1) Zhen Jiang Si (镇江寺滑坡) Landslide

Flooding had created a high water table in the slope and generated excess pore pressure which could not be dissipated fast enough when the river level was lowered. Landslide was initiated by downward movement at the slope toe and propagated to the middle height, thereafter, masonry wall was cracked and several houses tilted. The volume of this landslide was estimated to be about 300,000 m^3.

(2) Li Zi Ba (李子坝重庆仪表厂滑坡) Instrument and Meter Plant Landslide

Excessive man-made fill was placed on top of alluvium making a total thickness of 25 m above the underlying interbedded mudstone and sandstone bedrock. Slip surfaces follow the interface between the alluvium and the bedrock. Cracks (25 m long and 100 mm wide) were formed and displaced by more than 1 m, causing factory and retaining wall to crack. Every year when the flood returns, the movement of this slope reactivates. The volume of this landslide was estimated to be about 500,000 m^3.

(3) Li Zi Ba (李子坝小学滑坡) Primary School Landslide

This is a 9-m-thick fill slope which has been subjected to river erosion and undermining since 1950. In 1981, when the river flood level was quickly reduced, creep movement was observed in the fill body and the road above subsided and retaining wall cracked. In 1989, the road above the slope suddenly cracked (30–40 m long, 150–350 mm wide) and subsided by 1 m. Minor urgent stabilization work was carried out but up to this moment, detailed ground investigation work and mitigation measures had not been carried out. The volume of this landslide was estimated to be about 120,000 m^3.

(4) Wang Jia Po (王家坡滑坡) Landslide

This slope is 120 m long, 80 m wide and has a volume of about 60,000 m^3. It is a fill slope overlying the mudstone/sandstone bedrock. The fill body is composed of clayey sand with a mixture of gravel, boulder and construction debris. It was formed in 1957 from uncontrolled dumping during the construction of the nearby highway. Every year, during heavy rainy season, the fill saturates with water and moves. The last 30-year record shows that it has moved by 6–8 m and settled at 3 m. In July 1985, it had moved by 20–30 mm and cracks were developed inside the fill body and extended upward. Several houses on top of the slope developed cracks, threatening the lives of more than 100 people. Remedial works were carried out in 1981 and 1987, but new cracks continue to develop.

(5) Gao Jiao Stove (重钢高焦炉滑坡) Landslide

The slope is composed of soft clay overlain highly fractured rock mass. It was estimated that the internal friction angle of the sliding surface was about 8.5° and the sliding plane had an angle of about 2–5°. In 1958 when the river flooding level increase, 50 mm differential settlement was recorded. Several water holding tanks were cracked and some moved by 14.6 m and settled at 100–900 mm. The major cause of the landslide is due to river erosion undermining the toe, exacerbated by uncontrolled industrial water leakage into the ground. The area of the landslide was about 1,020,000 m^2, whereas the volume of this landslide was estimated to be about 14,200,000 m^3.

In Hong Kong, the most common slope failure mechanism involved shallow sliding of less than 3 m deep (Brand, 1985), most of which are caused by surface infiltration and erosion due to surface runoff. Other common modes of failure and mechanisms illustrated with reference to case histories can be found in Wong et al. (1998).

7. Mitigation measures

In Chongqing, typical stabilization measures, adopted to suit local ground conditions and local construction practice, may consist of the following:

1. trimming back to follow the sedimentary rock bedding;
2. hand-dug lateral resistance piles with or without pre-stressed ground anchors (see Fig. 7 for conceptual illustration);
3. reinforced concrete wall between lateral resistance piles (see Fig. 8 and Liu and Li, 1995 for conceptual illustration);
4. pre-stressed or passive ground anchors;
5. gravity masonry retaining wall and
6. slope surface protection including hydroseeding, sprayed concrete and reinforced concrete grids.

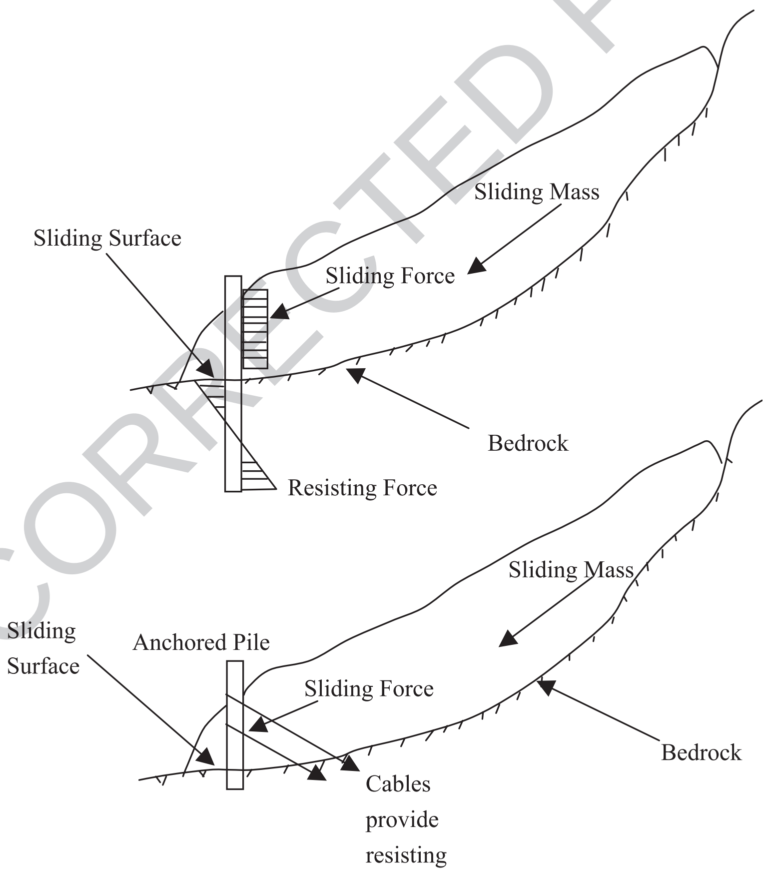


Fig. 7. Slide resisting piles.

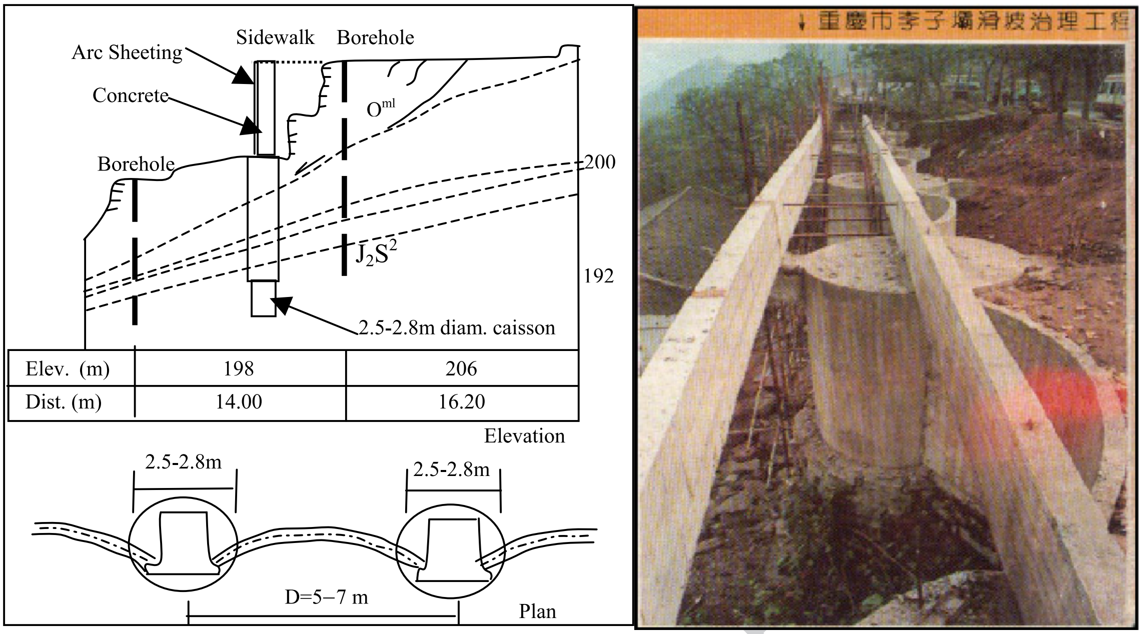


Fig. 8. Slide resisting piles integrated with concrete wall.

In Hong Kong, common stabilization measures may include a number of combinations as follows:

For soil slopes:

1. trimming and cutting;
2. retaining wall with or without tie-back;
3. re-compaction of fill slopes;
4. soil nailing;
5. mini-piles and
6. slope surface protection including hydroseeding, sprayed concrete and reinforced concrete grids.

For rock slopes:

1. scaling and trimming;
2. bolting and dowelling;
3. meshing and shotcreting;
4. buttressing and
5. anchoring (occasional).

Typical details of these stabilization measures can be found in CED (2002).

A review of the publications suggests that the use of piles to stabilize slopes in Chongqing is very common, whereas it is not commonly adopted in Hong Kong. The use of soil nails to stabilize slopes in Hong Kong is very common but not widely used in Chongqing. The rational being that the critical slip surface of the slope in Chongqing is usually deep and significant lateral resistance is required to stabilize the slope. In Hong Kong, the critical slip surface is usually very shallow, in the order of 3 m deep, and therefore, the use of soil nails is economical and feasible.

Ground anchors (whether active or passive) are commonly used in Chongqing because of deep critical slip surface and significant restoring force and moments are required. The use of active anchor is not encouraged in the industry in Hong Kong simply because of poor performance record (stress relaxation, poor workmanship and insufficient corrosion protection) and long-term monitoring requirement. The party responsible for long-term maintenance would normally select mitigation options that are monitoring-free and the use of active ground anchors would normally be discouraged unless technically it can be justified that there are no other alternative solutions.

The use of soil nails integrated with reinforced concrete tie beams or panels is gaining popularity in Hong Kong. The system would allow better distribution of resisting force, and confinement provided by the system would prevent surface erosion between the

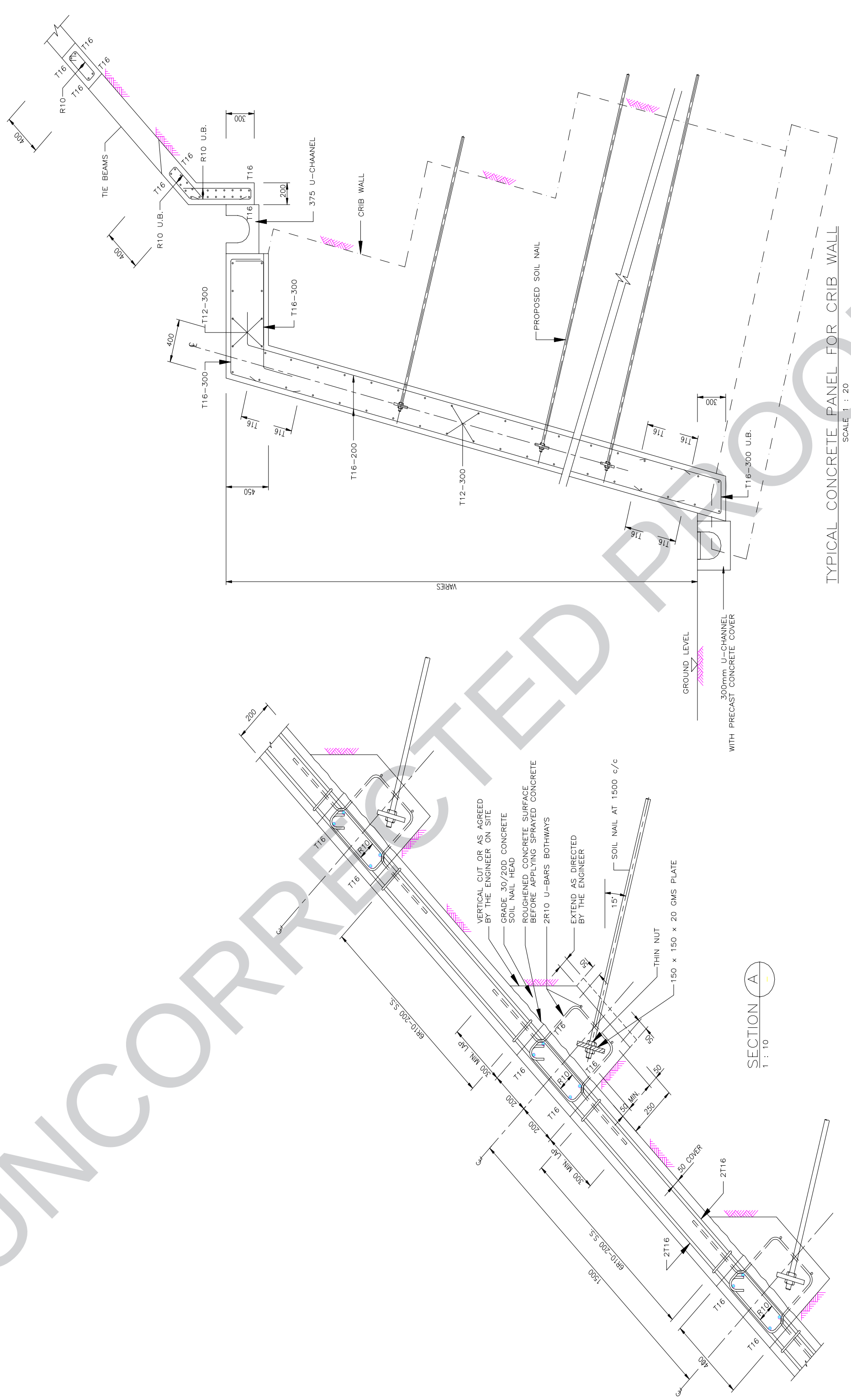


Fig. 9. Reinforced concrete panel.

soil nail's head. An example used by the author in Hong Kong is presented in Fig. 9.

8. Management and monitoring programs

The use of monitoring and observational approach (Li and Liu, 1995) is widely adopted in Chongqing to reduce the initial capital expenditure on mitigation measures. It also provides very useful data for back analysis of engineering parameters and failure mechanisms developed. In Chongqing, huge expenditure has been committed yearly to reduce the likelihood of landslide and managed under different level of governments. The Office for Landslip Prevention in Chongqing, similar to the Geotechnical Engineering Office in Hong Kong, is responsible for the design, mitigation, prevention, monitoring of landslide and rockfall and allocation of funding for emergency works.

In Hong Kong, the control and management of landslides is well established, and they are summarized in the following, which would serve as a good reference for Chongqing to develop their own management plan, taking into consideration their own financial budget and constraints.

1. Registration of all slope details so that a prioritization of mitigation measures can be given to slopes which deserve greater and early treatment.
2. Provision of a slope information system to the public so that they would be aware of the potential hazards of their surroundings and be responsible for maintaining and keeping the slope safe under their own property boundary.
3. Establishment of consultancy contract so that wider professional resources can be gathered to mitigate the slopes in a shorter period of time.
4. Establishment of external review board so that there could be a channel for technical exchange of latest development of technology and research.
5. Establishment of landslip warning system for early notification of potential hazards to the public so that people can stay away from slopes during heavy rain.
6. Establishment of emergency team so that professional staff can arrive at the landslide location in the earliest possible time to provide advice to evacuation and repair works and gather first-hand geological information for detailed engineering studies.
7. Identification of maintenance party of all slopes and enforcement of regular inspection, review and maintenance of slopes.
8. Provision of education to the public regarding proper registration, maintenance of slopes and reporting of landslides.

9. Conclusions

A review of the current geotechnical engineering practice in Chongqing and Hong Kong has been undertaken in this study. It is found that the city of Chongqing has a relatively larger landslide problem than Hong Kong due to the following elements:

1. The volume of landslide material is larger in Chongqing because it normally involves a deep-seated failure mechanism. The cost of mitigation measures is therefore higher because it requires heavy retaining structures or piles to resist the sliding mass.
2. Chongqing has to deal with landslides triggered by earthquake, river erosion and flooding.
3. The landslides in Chongqing would initiate at a much lower rainfall intensity than that in Hong Kong.
4. The prediction and monitoring of phreatic surface in Chongqing is more difficult than in Hong Kong because it is controlled by the network of joints and fissures in the discontinuities.
5. Observational and monitoring approach is widely adopted in Chongqing to reduce the initial capital investment on mitigation measures, whereas in Hong Kong, active prevention and stabilization measures are usually carried out to reduce the potential risk and long-term deterioration of the slopes.
6. The control and management of landslide in the city of Chongqing is in an immature stage largely due to financial constraints.

In terms of technical capability and achievement, it is conceived that both cities have been applying the practical and latest technology in mitigating the landslide problem.

It is recommended to the city of Chongqing that comprehensive long-term landslide management plan be established and in this respect, the system being used by the Geotechnical Engineering Office of the

Hong Kong SAR Government could be a good reference starting point.

10. Uncited reference

Liu, 1992
Yue and Lee, 2002

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