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Environmental Factors in Triggering Slope Failures

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Abstract : A variety of ground surface features which can generate high surface water concentrations during heavy rainfall resulting in slope failures in Hong Kong are described. They are named as environmental factors, many of which are created by or associated with human activities. Examples are platforms with parapet walls, road curves, surface and buried drains, unplanned vegetation, refuse and stockpiles of materials, excavation pits and trenches, adjacent slope failures, etc. Two typical failures triggered by adverse environmental factors are presented for illustration.

1 INTRODUCTION

In Hong Kong, rainfall intensities are very high. A large proportion of the rainfall becomes surface runoff. As the surface runoff travels downhill, it will be intercepted and concentrated by both man-made or natural ground surface features along its route. Concentrations of surface runoff are common during severe rainstorms. Figure 1 shows an example. Hundreds of slope failures occur as a result (Au, 1993). Those features which occur in the vicinity of slopes and cause excess surface water concentrations are called adverse environmental factors in the context of this paper and are described below.

2 SURFACE WATER CONCENTRATION

In Hong Kong, the average annual rainfall is about 2200 mm, over 80% of which is precipitated in the wet season between May and September. Intense rainfall is associated with troughs of low pressure or tropical cyclones during which short-bursts of high intensity rainfall as short as a few hours are common. It is not unusual for over 10% of the annual rainfall to be precipitated over a time span of several hours. During extreme rainstorms (approximately once every 10 years), the 24-hour and 1-hour rainfall intensity can exceed 400 mm and 100 mm respectively (Peterson and Kwong, 1981).

The majority of slope failures in Hong Kong are surface-water related in one way or another. Pore-water suction depletion, erosion and pore-water pressure build-up at shallow depths are the common failure mechanisms (Au, 1997). All these failure mechanisms rely on a quantity of water sufficient to cause the failure being present on slope surface. It follows therefore that as the concentration of surface runoff on a slope increases, the probability of failure of that slope increases. Hence, an increase in rainfall intensity increases both the number and the size of failures. This is especially true in urban areas because adverse environmental factors and steep man-made slopes are very common (Au, 1993).

Figure 1. An example of surface water concentration

3 ENVIRONMENTAL FACTORS

For a given slope where its uphill environmental factors give rise to a point for concentration of water, flooding or channelling of flow will occur (Au & Suen, 1991). As the environmental factors become more unfavourable, failure can be more readily triggered by lower rainstorm intensities and vice versa (see Figure 2). Many of the environmental factors are in fact created by or associated with human activities. Some of these factors may not come into effect until after a critical rainfall intensity has been reached, and thus the hazard which they pose may not be obvious beforehand. To give just a rough idea of their variety in the Hong Kong urban environment, some examples commonly encountered are cited:

3.1 *Platforms with Parapet Walls*

Terraced platforms bounded with parapet walls are common in Hong Kong, especially in old developments and in rural villages on steep terrain.

These parapets can often hasten flooding of the platforms if surface runoff discharge is blocked (e.g. Lumb, 1975 and case 2 below). Additionally, parapet walls usually have poor foundations, thus rendering them more susceptible to failure under severe flooding. When they fail, the foundations become exposed thereby allowing infiltration affecting walls and slopes below.

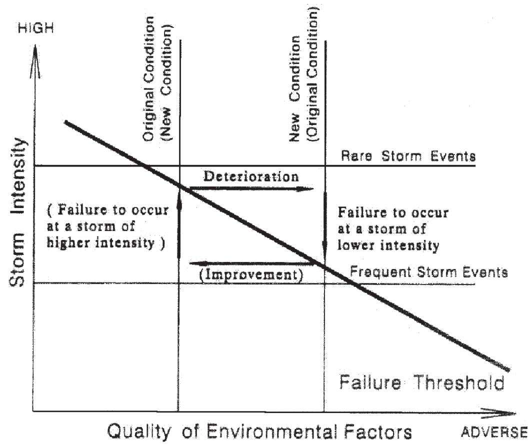

Figure 2. Relationship between storm intensity and environmental factors in triggering failure

3.2 *Road Curves*

A large number of roads in Hong Kong traverse hilly terrain, and intercept surface runoff from large upslope catchments. If the drainage facilities are inadequate or blocked, the intercepted surface water remains on the road surface and can accumulate. Spillage can most easily occur at spur bends where a kerb, parapet or any form of free board on the downslope edge of the road is absent or inadequate to prevent surface flow of high velocity along the road from overshooting the road. Hairpin bends are particularly vulnerable. Areas also vulnerable are valley bends with significant superelevation and high cambering which can cause flooding and overflow to develop on the downslope side of the road. A full account of the effect of road geometry on surface water hazards is given in Au & Suen (1991).

3.3 *Surface or Buried Drains*

Surface water is discharged by surface channels or buried drains. Unfortunately, even well designed and well constructed drains can become blocked due to refuse or natural vegetation. This point is elaborated in the next two sections. For surface channels, sections prone to overflow or blockage should be positioned away from locations of weak surface protection. Bends, merging points, catchpits, etc. should not therefore be built on or immediately above unprotected or poorly protected soils. Many failures in the past have been associated with this kind of poor drainage layout. In the case of buried drains, leakage occurs if joints open up or are displaced due to ground settlement. Installing buried drains in uncompacted fill is a practice that should be avoided.

3.4 *Unplanned Vegetation*

In Hong Kong, due to its tropical climate, natural vegetation can establish quickly. Vegetation can take root easily in soil debris or accumulated decomposed vegetation. Drainage channels that are not cleared can quickly become overgrown with vegetation, thus preventing their function as a drain. Creepers are common and can offer a surprisingly high resistance against tugging and flushing. The remains of large plants can quickly cause a blockage. The root development of trees or large shrubs near a channel may break or cause the channel to heave, hence throwing the channel out of level. Cracks in the drain may affect its hydraulic performance and allow vegetation to take root. Vegetation which takes root in cracks in chunam plaster (a soil/lime/cement mixture) which is commonly used in Hong Kong as a slope surface protection may speed up its deterioration. Certain species of natural vegetation with deep root systems may be able to completely lift and debond a large area of chunam cover, thus rendering it ineffective against infiltration and erosion.

Irregularities of a slope surface created by roots and trunks of trees, living or dead vegetation cover, etc. may also affect the flow of surface runoff and possibly exacerbate infiltration and erosion. Indeed, in severe rainstorms, slope failures can occur in densely vegetated areas (So, 1971).

3.5 *Refuse and Stockpile of Materials*

In Hong Kong, a huge quantity of refuse is created everyday both domestically and by industry. A comparatively small but nevertheless significant amount of this refuse ends up on open spaces, roads and natural terrain as a result of littering or illegal dumping. Litter is generally taken to comprise plastic bags, paper, rags, bottles and other small objects. Dumping may include larger objects such as timber, construction rubble, gas or chemical containers, abandoned cars, refrigerators, washing machines, etc. Littering and dumping are most common in squatter areas, abandoned sites, industrial estates or old developments. The chance of blockage to surface water drainage facilities is high in these areas.

Stockpiling of goods or materials may also block the surface drainage systems and render them non-functional. This situation is most common in construction sites and also in roadworks where construction or excavated materials are usually not adequately contained.

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3.6 *Excavation Pits and Trenches*

Major site formation works are susceptible to high surface water concentrations and these need no further discussion. Very minor roadworks, utility works and ground investigations in the form of pits or trench excavations, can also induce failures under severe rainstorm conditions. However, drainage and protective arrangements for such minor works are often neglected. Excavation pits and trenches can form sumps for surface water ingress, especially when they are close to the established flow path (e.g. side kerb gutters of roadways). If the backfill is insufficiently compacted, the pits remain as a potential area of flooding. Also as previously discussed, if the excavated materials are not contained and protected, they could be washed away and block the existing drainage. Au & Suen (1991) have reported a small pit excavation being associated with a major fill slope washout. Hence, even minor pit and trench excavations on and in the vicinity of slopes should be carried out and made good with proper consideration of the effects of heavy rainfall.

3.7 *Adjacent Failures and Others*

Debris from a slope failure may cause blockage to water flow and upset the original safe drainage pattern. Slope failures may therefore be liable to cause further failures. An example of this is failure debris from a slope overlooking a roadway blocking the runoff carried along it. A failure downslope of the roadway may be caused due to overflow generated by the blockage.

The above environmental factors are by no means exhaustive. These cases demonstrate that when assessing the potential problem of surface water concentrations, engineers must look beyond the boundaries of the slope or site concerned. Changes to existing environmental factors upslope of a slope or site may introduce new concentrations of surface runoff or destroy established ones. Thus, effects due to concentrations caused by activities such as construction works, drainage improvements, road works and the like upslope should not be overlooked.

4 CASE STUDY

4.1 *Case 1 - A Slope Failure*

A slope failure occurred on a cut slope of colluvial material supporting a level open platform which abutted a natural hillslope at its rear. A general view of the site prior to the failure can be seen in the stereo-pair aerial photographs in Figure 3. The failure occurred as a washout (see Figure 4) during an extremely heavy rainstorm (the highest 1-hour rainfall intensity was 100 mm/hr) at which time the 1 000 mm culvert, which served to intercept surface water discharged from the 30 000 sq. m upslope natural catchment area, had been blocked with sediments.

Figure 3. Stereo-paired aerial photograph of the site - case 1

The catchment area provided the source for a large quantity of surface water. The crest platform was bare and the chunam surface protective cover to the slope which subsequently failed had deteriorated. The topographic depression of the crest platform had allowed flooding of the platform and also overflow across the slope crest if the culvert was blocked (Figure 3). An examination of the site after the failure revealed that the sediments in the culvert were covered with vegetation suggesting that the culvert had been silted up for sometime. The vegetation had reduced the self-flushing capability of the culvert and exacerbated the blockage.

4.2 *Case 2 - A Retaining Wall Failure*

The failure of a retaining wall supporting a garden terrace occurred during the same storm. The failure is shown in Figure 5. The failure occurred at the front garden of one of the houses located at the end of a cul-de-sac road. A flat area at this end of the road provided car parking spaces (Figure 6) and this part of the road was collecting runoff from a fairly large catchment area.

Discussion with a resident of the house affected revealed that the wall failed as water overflowed the kerb line of the car park into his allotment. The car park was inundated by the surface runoff accumulating on the road. Drains serving the car park were either blocked or simply overwhelmed at the time. Considerable flooding occurred and water flowed towards the failed retaining wall as was evident from the level of dead leaves that had accumulated on the wire fences (Figure 7). The garden terrace was constructed with a parapet wall which promoted further flooding of the garden platform.

5 DISCUSSION AND CONCLUDING REMARKS

High concentrations of surface runoff are the cause of many slope failures in Hong Kong. Environmental factors causing high surface water concentrations should be removed or improved (see Figure 2).

Figure 4. General view of failure - case 1

Figure 5. General view of failure - case 2

Major concentrations can be prevented if water is properly discharged through appropriately designed drainage facilities. Open concrete U-channels are most commonly used in Hong Kong. However they will not function if they become blocked. As an alternative, a protective surface cover which can prevent infiltration, scouring and other destructive erosional effects from the surface water flow can be used. The effectiveness of the surface protection relies on its impermeability, material strength, weight, bonding with the underlying soil, and factors affecting its long-term durability. In Hong Kong, both chunam and shotcrete, reinforced or unreinforced, are most widely used for this purpose. Traditionally, surface drainage and protective covers are incorporated in new slope works. This is justified because of the heavy rainfall that occurs in Hong Kong. If the slope materials are not susceptible to infiltration or erosion (e.g. solid massive rock), of course no surface protection is needed. If high surface water concentrations will not develop, hydroseeding/turfing, which are more pleasant environmentally, may be used as slope surface protection.

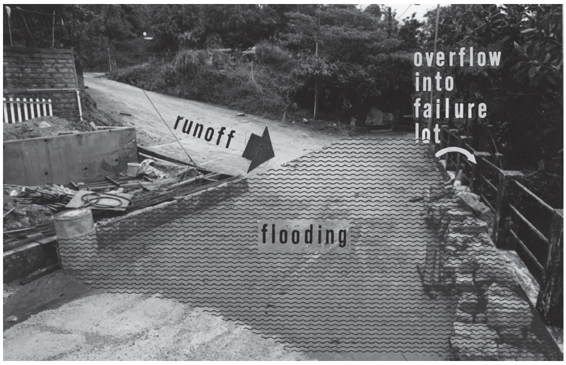

Figure 6. The carpark platform at rear of the houses - case 2

Man is the main creator of many adverse environmental factors. His involvement in an urban setting stems from a whole range of everyday activities. Natural phenomena such as the aging of surface protection, establishment of natural vegetation etc. are also responsible. Good planning and design of works, proper management of construction activities, continual maintenance of the drainage systems and surface protection, control of vegetation growth/destruction, control of stock piling and prevention of littering, etc. are vital in mitigating these surface water effects.

Hazards relating to environmental factors can only be effectively handled by application of good engineering techniques and careful judgement. Where they can be carried out safely, inspections during periods of rainfall are most useful as it is only then, when the less obvious but significant effects of many of the adverse environmental factors can be identified. For the same reasons, information offered by local

Figure 7. Accumulated dead leaves as evidence of overflow - case 2

residents and others who have seen the surface water concentrations should not be undervalued. For situations where a proper investigation is not possible, a more costly "broad-brush" approach of applying extensive and robust surface protection to the concerned area should be employed. Although slope problems of this kind are fraught with uncertainties and unquantifiable elements, it is yet possible for an experienced engineer to arrive at safe solutions even in very difficult cases.

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