Soil Pipes and Slope Stability in Hong Kong

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INTRODUCTION

A recent paper by Pierson (1983) provided sound evidence of the contribution of soil pipes to landslides. Whereas the existence of pipes has been documented in a good number of publications, their importance in the context of slope stability has not generally been appreciated. Attention is now focusing on pipes in Hong Kong as a major contributory factor to frequent landsliding.

PIPES IN HONG KONG

The hilly terrain of Hong Kong is prone to landslides brought about by the heavy seasonal rainfall (Lumb 1975; Brand 1984, 1985). The granites and volcanic rocks are weathered to considerable depths, the surface residual soil often being overlain by a mantle of colluvium. Until recently, it was not realized that the existence of pipes was an important factor in the overall stability of some of Hong Kong's hillsides, and that they have undoubtedly been the main cause of some of the failures that have occurred in Hong Kong cut slopes (Premchitt *et al*., 1985).

The pipes in the residual soils and colluvium of Hong Kong cover the range of types described in the Paper and discussed previously by Crouch (1976) and Jones (1981). They vary considerably in diameter, in length and in depth in the soil profile. In some cases, they are suspected of comprising anastomosing networks which cover large areas (Nash & Dale 1983).

Pipes in Hong Kong are most commonly exposed in shallow excavations in A and B soil horizons, as described by Crouch (1976). These are most commonly attributed to root holes and to animal burrows. They occur frequently on heavily vegetated slopes, especially in shallow depressions where water can concentrate.

The larger pipes observed in Hong Kong at exposed boundaries between colluvium and underlying in situ material are probably the most significant from the point of view of slope stability. Good examples of these are rarely seen, because the colluvium/in situ boundary is not often exposed over long lengths. The example shown in Figure 1 caused the hard surface protection applied to the cut slope in Chai Wan to be blown off; adjacent to this slope, a large pipe of this type was responsible for a landslide during heavy rain in June 1982 (Hencher *et al*. 1984).

Pipes also tend to form around boulders in colluvium or corestones in Hong Kong's residual soils, especially the granites (Figure 2). In their infant form, they appear as gaps of a few millimetres or more between boulders and the surrounding soil matrix. The rapid flow of groundwater around the boulders is almost certainly the cause of these. In the weathered bedrock mass, relict joints also undoubtedly influence the groundwater flow and aid the development of tunnel erosion.

In newly formed cut slopes in residual soil and highly weathered rock, pipes are often initiated along relict joints, which act as water paths both vertically and downslope. The groundwater percolates through these joints to some 'permeability' boundary, and a pipe is formed as the weathered matrix is eroded (through dispersion or abrasion) from the sides of the joint. The pipe can become enlarged to such an extent that the overlying material collapses into it, thereby producing a large eroded gully (Figure 3).

MODELS OF PIPE BEHAVIOUR

Only a few attempts have been made to model the effect of pipes on the hydrogeology of a slope. Pierson (1983) used a Hele-Shaw model to examine and demonstrate the effect of a single soil pipe on the overall flow regime in a slope. For many real situations, certainly those in Hong Kong, this type of analogue cannot be used to model the complexities of the network of flow channels produced by piping. Only a numerical model, of the finite difference of finite element type, is sufficiently flexible for this purpose.

A recent detailed study of a major hillside in a densely populated part of Hong Kong (Geotechnical Control Office 1982) produced some useful information on the effects of pipes on overall slope stability. The area was extensively instrumented with piezometers, many of them recording automatically. Rainfall and piezometric pressure changes at midslope in the unconfined colluvium aquifer over one 3-day period in May 1982 are shown in Figure 4. It can be seen that more than 300 mm of rain fell in one 24-hour period; some hourly intensities were over 50 mm. The piezometric pressure response in the steeply sloping colluvial aquifer was very rapid, a pressure head rise of almost 4 m taking place in 6 hours. In contrast to this rapid pressure increase, the decline in piezometric pressure took place much less rapidly, several days being required for complete dissipation.

Figure 1. Pipe in Hong Kong cut slope at the boundary between colluvium and weathered tuff, which caused the hard surface protection to be blown off

Figure 2. Pipe around corestone in weathered granodiorite

Figure 3. Severe tunnel erosion in colluvium initiated by a collapsed pipe

It is thought that the mechanism which accounts for the asymmetry of groundwater response depicted in Figure 4 is the rapid filling of a network of anastomosing pipes which are blank-ended, constricted or silt filled at depth. The response of the aquifer during the rainfall event was therefore rapid due to the infilling of large cistern-like voids. Recovery to equilibrium, however, was a slower process, facilitated only by the drainage of water from the void/pipe lining and thence via the soil matrix, which had an average permeability of the order of 10^{-5}m/s.

Leach & Herbert (1982) have described the numerical model developed for the hydrogeological study of the major hillside mentioned above. In order to simulate the measured field piezometric pressure changes with rainfall, it was necessary for horizontal/downslope flow to be invoked in the colluvium. The finite difference model was therefore provided with lateral connections between the colluvium nodes. The most likely explanation as to why this was found necessary during the calibration of the model is the presence of pipes in the colluvium which greatly increased its mass horizontal transmissibility. The effects of these pipes on slope stability analyses are therefore of considerable importance.

The determination of the extent and geometry of pipe networks in slopes is extremely difficult, as are predictions of pipe development and collapse. The normal site investigation methods are of little help in this respect, and reliance must be placed largely on

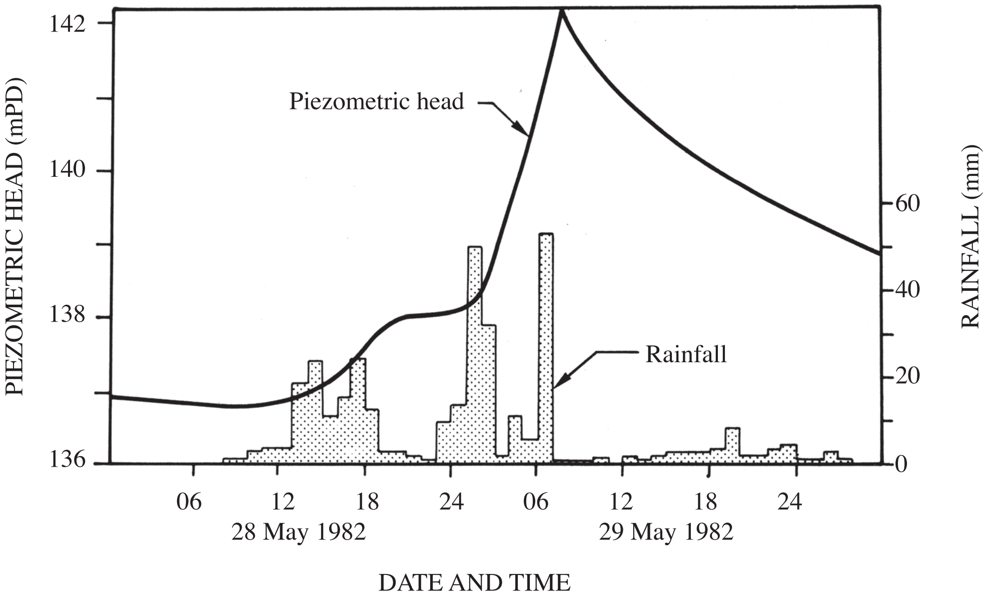

Figure 4. Influence of soil pipes on piezometric head response on a Hong Kong colluvial slope

examinations of exposures and surface features for an assessment to be made of the likely extent of pipes.

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