

Two Landslides in Hong Kong

A. J. Vail

Binnie & Partners (Hong Kong)

Synopsis: The terrain, climate and density of development in Hong Kong combine to create conditions of potential slope instability. This paper describes two landslides which occurred in recent years, from very different causes but with similarly disastrous consequences. The lessons learned in Hong Kong from these disasters are equally valid in other parts of the developing world. Although the first of the landslides described took place some twelve years ago, a review of the events is appropriate at this time when a new awareness to geotechnology is growing in those areas.

INTRODUCTION

The territory of Hong Kong, comprising 236 islands, the Kowloon Peninsula and the New Territories has a total area of 1060 sq km. Three-quarters of this is mountainous and the population, which now exceeds 5.3 million, lives in the other quarter, creating population densities which are among the highest in the world.

The long term average rainfall amounts to 2200 mm, 80% of which falls in the summer months between May and October, June and July being the peak months. Rainfall intensities can exceed 100 mm over a one hour period with peak intensities greater than 150 mm.

Hong Kong is a cyclonic area and, while typhoons can occur in any month, they normally arrive in the summer reaching a peak frequency in July and August. Typhoons do not, however, induce the highest rainfall intensities. These have been recorded during periods of monsoon rain which also occur in the summer.

GEOLOGY

The rocks of Hong Kong consist of rhyolites and granites covered to varying depths with a mantle of residual soil and colluvium. The granites are younger than the rhyolites and have been intruded into them in the form of batholiths with an irregular outline.

The rocks are tropically weathered to sandy, silty clays or clayey sandy silts, the soils derived from the granites being more sandy than those from the rhyolites whether they are formed by insitu weathering or by colluvial processes. The soil mantle can vary in thickness from a few metres to 50 m depending upon the slope angle, the water table and the soil type.

In Hong Kong, hill slopes of soil derived from the weathering of granite usually have an overall slope angle of about 30° and those of weathered rhyolites have an angle of about 25°

DEVELOPMENT

At the turn of the century, the population of Hong Kong numbered about 200,000. The influx of immigrants from mainland China brought this figure up to 1.6 million by the outbreak of World War II when the Japanese occupation reversed the trend and, at the cessation of hostilities, only 600,000 remained.

After the war the population again began to rise and, when the communist regime came to power in 1949, the influx of immigrants became a flood and the population reached 3.9 million by 1963 and 5.3 million in 1983. This rapid increase in the population over the past 35 years has created acute problems of housing.

Until recent years, private developers exploited every available piece of flat land on the Island and in the Kowloon Peninsula and as this all became taken up, encroached into the hillsides cutting access roads and platforms for more dwellings with little understanding of the effect this had on the stability of these hillsides.

In the late 1950s, in response to an acute housing shortage caused by the influx of refugees, the Hong Kong Government initiated an ambitious programme to provide large housing estates for the homeless. Before building construction could begin, platforms had to be formed in the sloping terrain. This site formation included large cuts and fill embankments, some more than 40 m high. Speed of construction was of the essence and, as a consequence, fill was often end tipped and not properly compacted. In many cases the embankments straddled valleys in which inadequate provision was made to maintain the natural drainage in the valley.

Over the years there were a number of failures in these cut and fill slopes. These normally occurred during severe and prolonged rainfall, when the slopes were saturated and when ground water tables were higher than normal. These failures tended to be looked upon as an inevitable outcome of heavy rain and were treated symptomatically as they occurred. Some of the failures were large and, because they occurred without

warning, or at least without recognition of the warning signs, their results were disastrous and the loss of life was high.

THE PO SHAN ROAD LANDSLIDE

History of the site

In 1962, a developer acquired a plot of land, Lot 2260, of about 3,000 sq m between Po Shan Road and Conduit Road (Figure 1). Because he wanted to redevelop the site to produce the maximum floor area permitted under the regulations, which also restricted the height of the structure, the developer excavated into the hillside to permit the construction of a nine storey building over a substantial part of the site. The excavation for this building was completed in 1963.

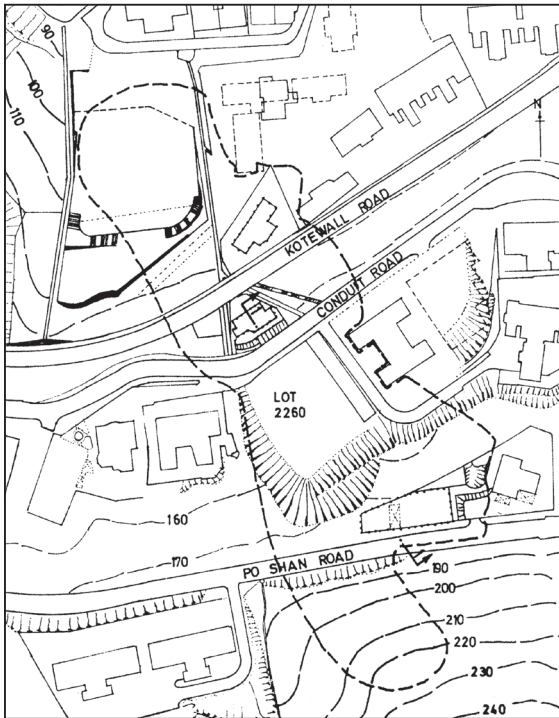


Figure 1. Po Shan Road Landslide. The shaded area shows the extent of the landslide and the limits of the debris (Commission of Inquiry 1972)

Following a change in the management of the developing firm and of the architect, revised plans for a greater floor area were prepared and submitted to the authorities but it was not until 1970, seven years later, that this application succeeded and he was permitted a development of 12 storeys but with the same height limit. On the basis of this permit he planned to excavate deeper into the hillside with the intention of accommodating carparks at a reduced

ground level. These new site formation works involved the formation of an unsupported cut slope of 80° some 13 m below an existing slope which supported Po Shan Road running above and behind the site (Figure 2).

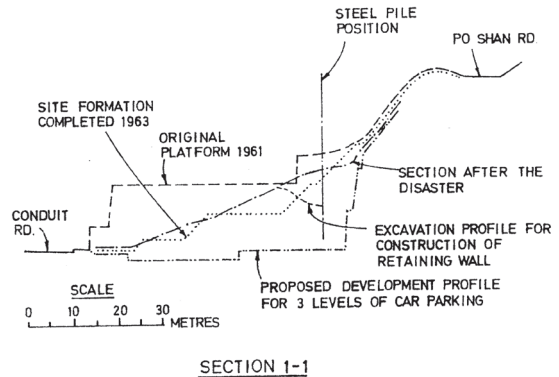


Figure 2. Section through Lot 2260

The contractor appointed for the additional site formation began work in May 1971 but stopped after only a few days because, as he advised the developer, he felt that the proposed slope was dangerous. During the ensuing months a number of slips occurred in the exposed slope and residents of the adjoining properties became alarmed. In response to public pressure, the authorities then required the developer to stabilise the slope. In March 1972, sheet piling was driven along the toe of the slope to support the sides of a trench for a retaining wall, the slope face was protected from infiltration by metal sheets supported on a bamboo scaffold.

In May, cracks appeared in Po Shan Road and were sealed by the Highways Department. Sheet piling and trench excavation continued until 15th June 1972 when heavy rain prevented further work. The heavy rain continued on 16th and 17th when the whole width of the cut slope behind the piling slipped, buckling the piles and carrying away the metal sheet covering. During the day the sheet piling continued to distort and deflect and half the width of Po Shan Road above the site settled some 2 m. The heavy rain continued on 18th and had increased further in intensity by midday. The subsidence of half Po Shan Road continued and the level difference reached 6 m.

At about 5 pm, a mass of earth, rock and vegetation broke away from the south-west corner of the site flowed across Conduit Road to the north and half buried a four storey house between it and Kotewall Road.

At about 9 pm the major landslide took place in the hillside above Po Shan Road taking with it the slope behind the site together with the road. It engulfed and obliterated the four storey building struck by the previous slide, crossed the lower road and struck a

13 storey building ‘Kotewall Court’ which appeared to shudder, come away from its foundations and then to topple and break up transversely near the middle as a witness described, “like a man kneeling, then falling forward”. In falling, the building struck and damaged the corner of an adjoining block of flats and then crumbled and disintegrated killing 67 people and injuring 20 others.

The slide, some 120 m long and 67 m across, with an average depth of 10 m was estimated to contain about 80,000 tons of material. It took from 7 to 10 seconds to complete its travel (Vail & Attewill, 1976).

Topography and Geology of the Site

The hillside above Po Shan Road is of rhyolite covered by a mantle of colluvium between 20 m and 30 m thick. The hillside forms a distinct ridge and is among the steepest in the area with an overall slope of 36° down to the centre of lot 2260 where it meets the shallower 18° coastal slope. The material in the hillside consists of about 2 m of sandy silty clay overlying sandy clayey silt containing subrounded boulders. A number of boulders on the surface of the hillside appear to have migrated from the summit. Samples taken from the slipped material show 10% of clay and 30% of silt (Figure 3).

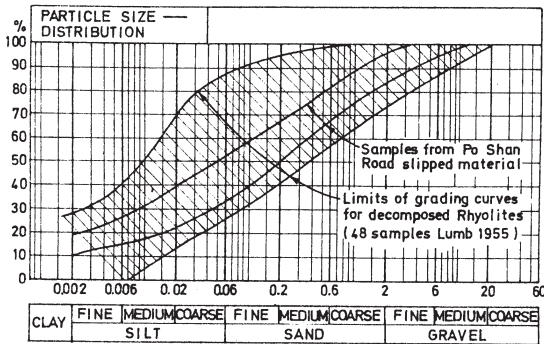


Figure 3. Grading band of samples recovered from Po Shan Road (Vail 1972)

The cause of the landslide

A number of unfavourable factors combined to cause this landslide. These were:

- (1) The slope and nature of the material forming the hillside.
- (2) The almost unprecedented intensity of the monsoon rainstorm of 16th, 17th and 18th June.
- (3) The deep cut in lot 2260, the developer’s site.

In 1972, 82 years of rainfall records were available. These showed that, for each of the periods January-June, April-June and May-June, 1972 was the second wettest year on record having been exceeded only in 1889. In 1972, the wet season began on 1st May and

rain fell almost every day from then until 15th June when it became intense and persistent. Over 200 mm fell on each of 16th, 17th and 18th June.

These three days of intense and prolonged rainfall with their peak intensities on 17th and 18th saturated the ground to an extent unprecedented for very many years. The result that its shear strength was reduced to a minimum value. It may well be, too, that rain infiltrating into the hillsides higher up had reached the comparatively permeable zones of insitu weathered material immediately overlying bedrock and had percolated downwards inducing high pore pressures at the lower level of the landslide area.

The excavation of lot 2260, which began in 1965, was increased in May 1971 and again in May 1972, must have progressively reduced the stability of the hillside above and below Po Shan Road.

THE SAU MAU PING LANDSLIDE, 1976

History of the site

In 1962, the Government of Hong Kong let a contract for site formation for a large resettlement estate at Sau Mau Ping in Kowloon. This site formation contract included a number of embankments to provide platforms in the sloping terrain for the construction of multi-storey blocks of flats at both their crests and their toes. In general, embankments were built at

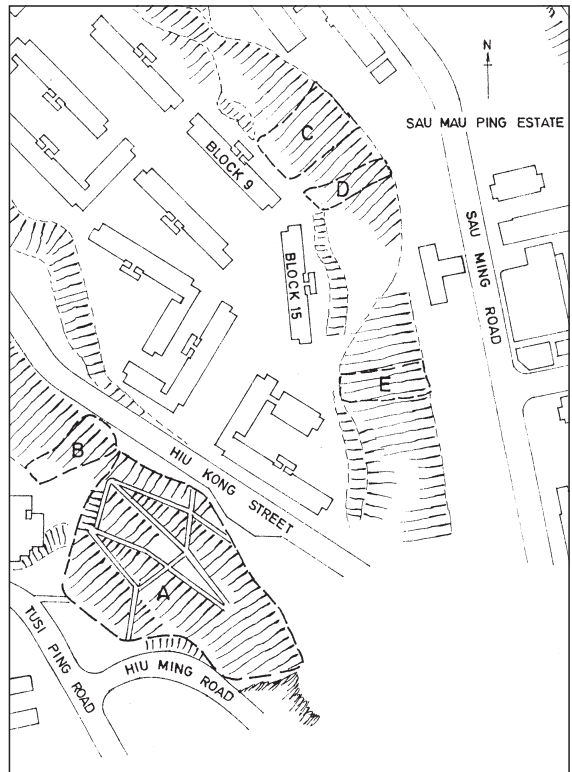


Figure 4. Part of the Sau Mau Ping Estate

slopes of 1 on 1.5, or 34°, as was common practice for the much smaller highway embankments which had been constructed up to that time. The slopes on this estate however were up to 35 m high. Their surfaces were grassed and they had no intermediate berms. Subsequently stone pitching was placed on the surface for about a third of the height of the slope.

Figure 4 shows part of the estate at Sau Mau Ping. In 1972, on the same day as the failure at Po Shan Road but some 8 hours earlier following a period of maximum intensity reaching 67 mm/hour, the fill slope marked A on Figure 5 failed. In failing the material liquefied and inundated a squatter village at the toe of the slope burying 71 people. The failure was described by an eye witness as “sliding like a carpet”.

At about 9 am on 25th August 1976, following 24 hours of heavy rain deposited by Tropical Storm Ellen, a section of the embankment behind Block 9 of the Estate 42 m wide, failed over the total slope height of 35 m and to an average depth of about 2 m. The disturbed material liquefied on failure, poured down the slope, across a courtyard and slammed into the back of Block 9, a six storey shop house and residential block entirely filling the rear ground floor rooms to ceiling height and engulfing 18 people (Morgenstern, 1978, 1980). This slope was described by a witness as “sliding like a sheet”. Within 15 minutes of the failure behind Block 9, marked C on Figure 4, slopes also failed at points B, D and E.

Tropical Storm Ellen

The records of the Royal Observatory and study of their report on Tropical Storm Ellen and other rainfall indicate that this rainstorm was the most severe that the Sau Mau Ping Estate had experienced since it was constructed in 1963.

Figure 5, shows the maximum twenty-four hour cumulative rainfall for this rainstorm together with those for the only two comparable rainstorms in the period of record, in August 1966 and June 1972.

The rainfall shown is that recorded at the Royal Observatory for all three storms together with the average of Tate’s Cairn and Kai Tak Airport for the August 1976 storm as these are nearer Sau Mau Ping and reveal, a higher 24 hour total and higher intensities.

It can be seen that the 1966 rainstorm produced the highest intensity of 108.2 mm per hour followed by the 1972 rainstorm with 98.7 mm per hour. In the 1976 rainstorm there were two periods of high intensity, the first, after some 14 hours of rain, was recorded as a maximum of 57.5 mm per hour at Kai Tak and the second, after 22 hours, was recorded as a maximum of 51.5 mm per hour at the Royal Observatory. It was after the second of these periods of high intensity that the 1976 Sau Mau Ping landslide occurred.

Although the maximum intensity of rainfall recorded at the Royal Observatory in the 1976

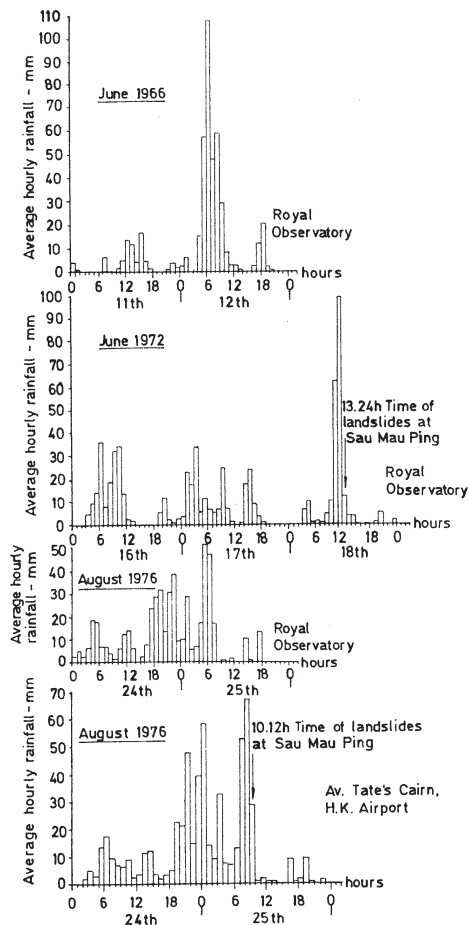


Figure 5. Average hourly rainfall at The Royal Observatory and Tate’s Cairn - Kai Tak

rainstorm was less than that in the 1966 and 1972 rainstorms, the total maximum twenty four hour rainfall was greater, amounting (at the Royal Observatory) to 445.1 mm in 1976 as opposed to 422.4 mm in 1966 and 232.7 mm in 1972. The total recorded at Kai Tak in 1976, 513.0 mm, was higher than at the Royal Observatory suggesting that the precipitation at Sau Mau Ping might have also been higher than at the Royal Observatory and that, therefore the maximum intensity might well have been higher.

The Embankment

A study of the general and particular specification in the contract under which the Sau Mau Ping embankments were constructed reveals that the contractor was required to place the fill in five foot layers and to compact it “to the approval of the engineer”, he should make allowances for consolidation and shrinkage and where materials

“of widely divergent characteristics are drawn from different borrow areas, those of the lowest bearing value shall be placed at the bottom and those of highest bearing value being placed at the top”.

The particular specification added that “All filling slopes shall be thoroughly moistened and compacted by power rammers to the satisfaction of the engineer before any turf or surface channels can be laid”.

Immediately after the landslide, twelve samples of the failed material and four from the undisturbed ground adjacent to the slip scar were taken in a standard core sampler from which the insitu dry density and moisture content were determined. Additional samples were taken for grading Atterberg limits and British Standard density tests. The insitu dry density of each core sample was expressed as a percentage of British Standard and the field moisture content was compared with the standard optimum.

Consolidated drained triaxial tests were carried out on saturated remoulded samples of material from the failed area at dry densities of 80% and at 95% of British Standard density achieved at optimum moisture content plus 3%. The shear strength parameters derived at these densities were:

	80%	95%
c'	0	3.5
ø'	33.5°	34.5°

An infinite slope analysis, using the lower density parameters, indicate a factor of safety very close to unity against shear failure assuming zero pore pressures.

Trial pits on the site, in which insitu densities were determined revealed stratification of the fill parallel to the face of the slope and density tests indicated densities slightly lower than those indicated by the core samples tested immediately after the failure. The “critical density” defined as the density above which collapse will not take place on shearing was determined by a number of methods (Beattie & Lovegrove, 1977) and in nearly every case the insitu density was found to be below the critical density. This gave quantitative evidence to support the observation that the fill had liquefied on failure.

The causes of the failure

While the rainstorm on the 24th and 25th August 1976 did not produce the greatest intensity that the embankment had endured, it did produce the highest maximum 24 hour precipitation which included two periods of intensity exceeding 50 mm per hour. The landslide occurred at the end of the second of these periods of high intensity rainfall, at the end of the maximum 24 hour period. It is interesting to observe that the landslide at Sau Mau Ping in 1972 occurred after 11¹/₂ hours of (even more) intense rainfall but

the incidence of rainfall being so localised it may well be that the two periods of intensity in the 1976 rainstorm were higher than was recorded at the Royal Observatory and at Tate’s Cairn - Kai Tak.

The shape and mode of failure of the 1976 landslide suggests that the embankment had become completely saturated to or beyond the depth of the failure by what was, in the life of the Sau Mau Ping Estate, a period of exceptional rain and that this rain had reduced the apparent cohesion of the embankment material and had increased its weight to the point of instability.

The soil tests of samples taken from the embankment in and adjacent to the area of the landslide show that the dry density of the material in the embankment immediately below the surface and the failure surface was within the range of 75 to 86% of British Standard dry density and had an average of 79%. This density is well below the normally attainable values of 95 to 100% and confirms that the outer three metres, at least, of the embankment had not been adequately compacted.

The triaxial test results, although taken on only two samples and albeit open to some differences in interpretation because of excessive sample strain, do give results consistent with the shape of the failure surface which, being very shallow, is typical of the mode of failure of a cohesionless soil. The effective friction angle is almost exactly that of the embankment and, if groundwater flow developed in the outer surface of the embankment, with the consequent rise in pore pressure, the factor of safety would have been reduced below unity very quickly.

There is little doubt that the cause of the failure was the rainfall from Tropical Storm Ellen combined with the low insitu strength of the embankment fill caused by inadequate compaction. The fill was so loose that, in fact, its density was below the critical value for the material and this was the sole cause of it liquefying and flowing into Block 9 with the consequent loss of life.

LESSONS TO BE LEARNED

One has only to fly over the uninhabited parts of Hong Kong to see the slip scars in the natural hillsides giving ample evidence that much of the terrain is, at times, in a state of limiting equilibrium as the landscape undergoes the processes of geomorphological evolution.

Since the territory was first colonised in the last century, landslips have been a part of life and have been accepted as such. As development has progressed and man has interfered with the natural slopes, the slips have increased in number and have become more severe. Just as the early failures of natural slopes were accepted, so were the later failures in man made cuts and fills. In 1925 a highly developed and terraced

section of the Mid-levels in colluvium, not too far from Po Shan Road, failed catastrophically killing an estimated 150 people. In 1966 a man made fill slope behind Victoria Mansions failed and a mudflow inundated the car park below the block. This flow was, in all probability, a case of liquefaction.

The rainfall disasters of 1972, of which Po Shan Road and Sau Mau Ping were only two, awakened the public to the problem of landslides and the Governor appointed a Commission to enquire into them. The Commission's report drew the attention of developers, architects and engineers in Hong Kong to the dangers inherent in excavation or superimposition of additional loads on sloping ground without careful analysis and design to maintain its stability.

It also highlighted the fact that the understanding of the mechanism of tropical weathering and its effect on slope stability was imperfect and recommend a tightening up of Government control of development.

When, four years later, the second Sau Mau Ping landslide occurred it was clear that, although the danger of failures in natural hillslides was now understood and it was being combated, the problem of man made slopes had not yet been fully recognised and tackled.

The Government therefore appointed an independent panel of geotechnical experts to determine the causes of the recent failures in man made slopes, to assess the risk of future failures, suggest landslide preventive measures and to provide guidelines for future design.

The report of the panel established that, while Hong Kong had for some time recognised the need for careful control in placing fill in, for example, dam practice, this knowledge was not being applied to site formation with the result that fills were being placed in a loose state.

The report identified formally for the first time in Hong Kong the phenomenon of liquefaction and demonstrated how it could be avoided. It recommended methods for stabilising slopes of loose fill, for protecting them from direct infiltration of rain and from the build up of ground water. The panel reinforced the 1972 Commission's recommendations for stricter Government control of geotechnical engineering.

As a result of the reports, Hong Kong has swung from a pragmatic acceptance of landslides as acts of God to an acute awareness of geotechnical problems, the factors affecting stability, the precautions required in embankment and cut slope design and the need for constant surveillance and maintenance.

Following the recommendations of the 1972 Commission of Inquiry and the Independent Panel in 1976, the Government has taken the initiative in this Geotechnical awakening and has set up a Geotechnical Control Office of 128 Geotechnical Engineers and Engineering Geologists within the Engineering Development Department.

The Office undertakes a wide range of geotechnical engineering activities related to the safe and economic utilisation and development of land, particularly with the stability of existing and proposed slopes. It investigates the stability of existing slopes, designs and constructs landslide preventive works to public slopes and makes recommendations for preventive works to private slopes. It exercises geotechnical control over both public and private developments by checking the geotechnical aspects of the designs and the standards of site supervision.

The few brief years since the landslides described in this paper are insufficient to show that we have completely conquered the problem but at least we have a better understanding of them. Even if we have not completely eliminated the danger of future landslides we have, hopefully, significantly reduced their number and their consequences.

ACKNOWLEDGEMENTS

The author would like to thank the Director of Engineering Development, Government of Hong Kong for permission to publish this Paper.

REFERENCES

- Beattie, A.A. & Lovegrove, G.W. (1977). Proc. of the 9th I.C.S.M.F.E., Tokyo, vol. 3, pp 427-428.
- Binnie & Partners (1976). Report on the Slope Failures at Sau Mau Ping, 25th August 1976.
- Commissions of Inquiry (1972) - Rainstorm Disasters, 1972, H.K. Government Printer.
- Morgenstern, N.R. (1976). Mobile soil and rock flows. Geotechnical Engineering, vol. 9, pp 123-141.
- Morgenstern, N.R. (1980). Factors affecting the selection of shear strength parameters in slope stability analysis. Proc. of the International Symposium on Landslides, vol. 2, pp 83-93.
- Vail, A.J. & Attewill, L.J.S. (1976). The remedial works at Po Shan Road. Hong Kong Engineer, vol. 4, no. 1, pp 19-27.
- Vail, A.J. Final Report of the Commission of Inquiry into the Rainstorm Disaster 1972. Appendix V Government Printer, Hong Kong.