Relationship between Rainfall and Landslides in Hong Kong

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Synopsis: Hong Kong's steep slopes of deeply weathered rocks are prone to landslides during heavy seasonal rainstorms. The annual rainfall for 1982 was the highest for 100 years, and two major rainstorms occurred in May and August causing over 1 500 landslides. Another major storm in June 1983 caused more than 150 landslides. An automatic raingauge system linked to a central micro-computer allowed continuous monitoring of these storm events and enabled correlations to be made between rainfall and the occurrence of landslides. These correlations demonstrate that landslides in Hong Kong are heavily dependent on the magnitude of the short period rainfall intensity, with a threshold value of about 70 mm/hour. The antecedent rainfall pattern has been found to be of little significance.

INTRODUCTION

Rainfall is the most common cause of landslides, either directly or indirectly (Derbyshire, 1976). There are some good publications which illustrate the general relationship between landslides and rainfall in various countries, including Brazil (Barata, 1969; Guidicini & Iwasa, 1977), Italy (Rossetti & Ottone, 1979), Japan (Onodera et al, 1974; Fukuoka, 1980), New Zealand (Eyles et al, 1978; Eyles, 1979; Crozier & Eyles, 1980) and the United States (Campbell, 1975). The New Zealand studies are particularly noteworthy.

Landslides are a continual problem in Hong Kong, and they have caused heavy loss of life and major property damage in the past. It is estimated that more than 90% of Hong Kong's landslides are the direct result of major rainstorm events, the remainder being caused by such things as burst watermains or construction activity. On average, a significant landslide event, comprising numerous landslides and appreciable disruption and damage, can be expected to occur every two years. The temporary, flimsy dwellings occupied by squatters on many of Hong Kong's steep hillsides are particularly vulnerable to landslides.

Many types of slope feature are prone to landslides, including soil cut slopes, rock cut slopes, earth fill slopes, retaining walls, natural slopes and boulders. Fill slopes have been a major cause of casualties in Hong Kong in the past because liquefaction of loose fill caused mud avalanches (Morgenstern, 1978), but this problem has now been dealt with under the Government's programme of landslide preventive measures. The majority of significant landslides now occur largely in cut slopes (Lumb, 1975; Brand, 1982, 1984; Hencher et al, 1984).

It is very rare for detailed information to be available anywhere in the world on the geographical distribution and short-term intensities of rainfall, measurements of rainfall commonly being made on a daily basis at stations which are far apart. It is also rare for the precise times to be known for the occurrence of landslides. All previously published analyses of landslide data have therefore been based upon regional correlations of landslides with one-day or longer duration rainfalls, the more sophisticated correlations taking account of the antecedent rainfalls for periods of up to several weeks. This is true of the work carried out earlier in Hong Kong by Lumb (1975, 1979), who established some useful correlations between the number and severity of rainfall events and the daily and 15-day antecedent rainfalls.

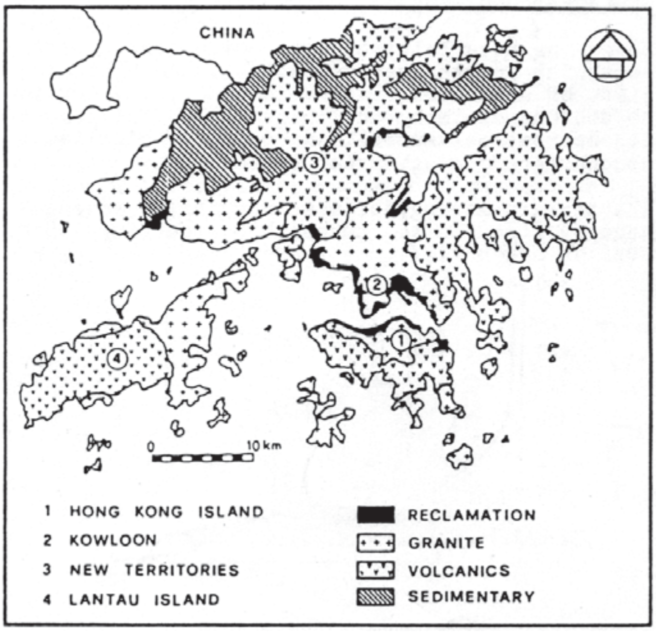


Figure 1. Territory of Hong Kong showing geology

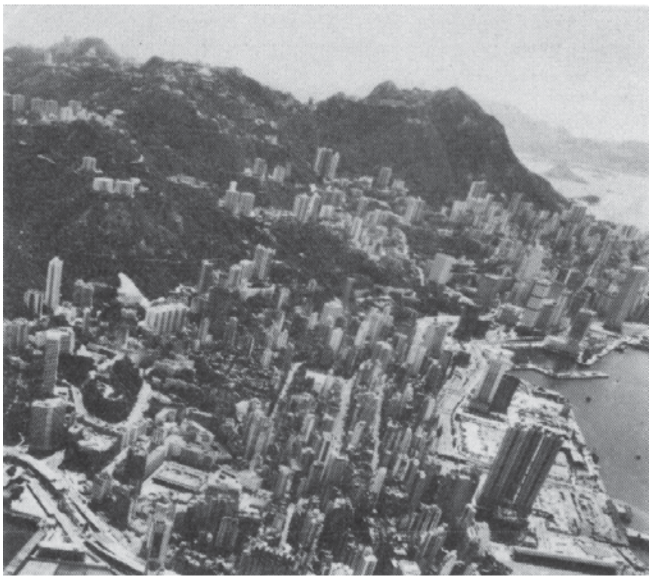


Figure 2. View along north coast of Hong Kong Island

The installation of a number of automatic raingauges in Hong Kong, and the collection of accurate data on the times at which landslides occurred in the past twenty years, has recently enabled correlations to be made between rainfall and landslides which were not hitherto possible. The results obtained from these analyses are of major significance, not just for Hong Kong but for other countries where rain-induced landslides are a recurring problem.

GEOGRAPHY AND GEOLOGY

Hong Kong is a British Crown administered Territory with an area of only 1 050 sq km. It consists of a number of small islands and a portion of the Chinese Mainland (Figure 1). The population approaches six million, most of which is concentrated in six urban areas.

The terrain is rugged, with many hills rising steeply from the sea to heights exceeding 400 m (Figure 2). Figure 3 shows the Territory's distribution of land area with elevation, and Figure 4 gives the distribution of terrain angle for Hong Kong Island and the Kowloon peninsula. An indication of the scarcity of land is the fact that about one-half of the flat terrain (0 to 5° is reclaimed from the sea. In general, under extreme rainfall conditions, much of the terrain which is steeper than 30° is liable to become unstable; this is in keeping with the situation that exists in Japan (Onodera et al, 1974).

In recent years, slopes for new projects in Hong Kong have been designed to acceptable geotechnical standards by means of classical analysis (Geotechnical Control Office, 1984). The majority of old cut slopes, however, were formed on the basis of empirical criteria established by practice, and many of these still stand at angles as high as 70°. Reference should be made to the publications by Lumb (1975), Brand (1982, 1984), Brand & Hudson (1982) and Hencher et al (1984) for descriptions of Hong Kong cut slopes.

The geology of Hong Kong has been described by Ruxton (1960) and Allen & Stephens (1971). The predominant rock types are granite and volcanic rocks (Figure 1). Granite predominates in those areas of the Territory which are heavily developed. Complete weathering of the parent rocks has resulted in the formation of mantles of residual soil, which are up to 50 m thick over the granite and up to 20 m thick over the volcanics. These commonly contain corestones of less weathered material. The typical weathered profiles of Hong Kong have been described by Ruxton & Berry (1957) and Lumb (1975), and some properties of the residual soils have been reported by Lumb (1965).

Of particular significance for the slope stability problems of Hong Kong is the presence of extensive bodies of colluvium which cover many of the footslopes. Colluvium is a slope debris material which is extremely variable in composition but which most commonly consists of boulders, cobbles and gravel in a matrix of sand, silt and clay. It is often in a loose state, and it frequently gives rise to perched watertable conditions. The colluvium is up to 30 m thick, sometimes with a boulder content as high as 50%.

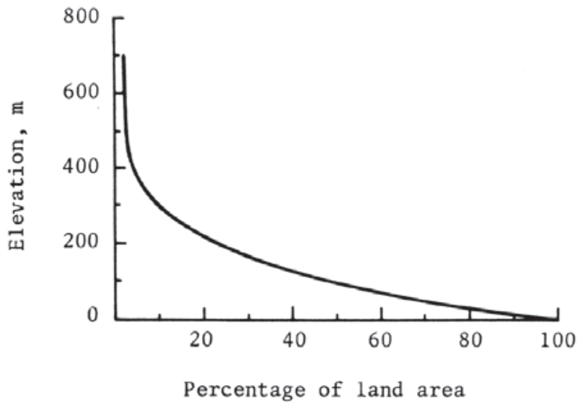


Figure 3. Distribution of land area with elevation

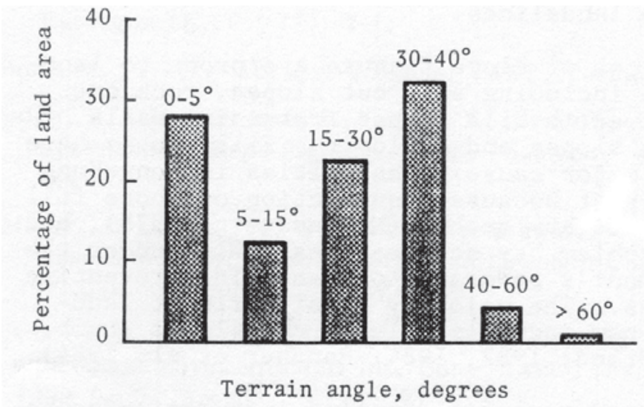


Figure 4. Distribution of terrain angles for Hong Kong Island and Kowloon

Table 1. Thirteen major rainstorm events in Hong Kong, 1963-1983

Date of Rainstorm	Type of Storm	Maximum Rainfall, mm				Landslide Consequences			
		Observatory		Other location		No. failures reported in newspapers*	No. Fire Services reports	No. people killed or injured	No. people permanently evacuated
		24-hour	1-hour	24-hour	1-hour				
24-25 August 1976	STS Ellen	416	52	500	82	314	23	57	2400
12 June 1966	trough	401	108	525	157	100	30	35	8500
29 May 1982	trough	394	44	430	111	498	15	48	8000
16-17 October 1978	STS Nina	380	37	380	38	15	1	1	no record
16 August 1982	STS Dot	362	68	370	95	62	6	9	1500
17 June 1983	trough	347	69	460	101	114	5	2	600
27 September 1965	TS Agnes	333	47	333	47	9	4	4	200
17 August 1971	Typhoon Rose	328	63	328	63	10	5	7	no record
12-13 October 1964	Typhoon Dot	304	60	375	94	8	10	39	8000
12-13 June 1968	trough	287	100	343	143	10	7	27	200
16-17 June 1972	trough	280	36	560	71	> 15	15	21	} 7800
17-18 June 1972	trough	275	99	300	98	"dozens"	14	229	
17 May 1972	trough	271	79	377	92	"dozens"	2	0	6000

TS = Tropical Storm
STS - Severe Tropical Storm

* It should be noted that these figures are for comparison only - they represent the lower limits of the numbers of landslides that actually occurred.

RAINFALL

Records of rainfall in Hong Kong have been kept since 1884 by the Royal Observatory. The average annual rainfall is 2 225 mm, with a minimum of 901 mm (1963) and a maximum of 3 248 mm (1982). The distribution of rainfall throughout the year is shown in Figure 5, where it can be seen that 80% of the rain falls from May to September.

Extreme rainfall events in Hong Kong are nearly always associated with atmospheric disturbances (Bell & Chin, 1968). There are two main mechanisms - tropical cyclones and troughs of low pressure.

Tropical cyclones, which are accompanied by gales ('tropical storms' or 'severe tropical storms') or by winds up to hurricane force ('typhoons'), can occur from May to November but are most common from July to September. Gales are experienced once a year on average, but a mature typhoon passes close to Hong Kong less frequently than this. Extreme rainstorm events associated with tropical cyclones last from a few hours to several days.

Troughs of low pressure that separate different types of air mass are common features of less extreme but heavy rain situations. Slow-moving troughs usually cause more extensive rainfall than tropical cyclones, and the rain is also more persistent. The primary meteorological feature is a relatively stationary trough of low pressure much larger than its constituent individual thunderstorm cells, which results in intense thunderstorm rainfall being superimposed on a large area of background rainfall. Rainfall associated with a trough of low pressure normally lasts for two days or more.

Rainfall intensities in Hong Kong can be high. 24-hour rainfalls of more than 250 mm occur fairly frequently, and one-hour intensities of more than 50 mm are not uncommon. The maximum 24-hour rainfall recorded at the Observatory is 697 mm (in 1889), and the maximum one-hour figure recorded anywhere is 157 mm (in 1966).

Table 1 lists the thirteen heaviest rainstorms in Hong Kong in terms of 24-hour rainfall over the past twenty years, together with their landslide consequences. Of these thirteen rainstorms, seven were associated with troughs of low pressure and six were caused by tropical cyclones. It should be noted that there are no adequate records to show the actual numbers of landslides that occurred during these thirteen rainstorm events. The small numbers of Fire Services reports are indicative of the numbers of particularly serious incidents (see below), whereas the numbers of landslides reported in newspapers are closer to (but still well below) the actual figures and give some relative measure of the number of failures that resulted from each rainstorm.

A few additional notes of explanation are required for Table 1. The number of people killed and injured is not necessarily proportional to the severity of a particular rainfall event, since a few individual

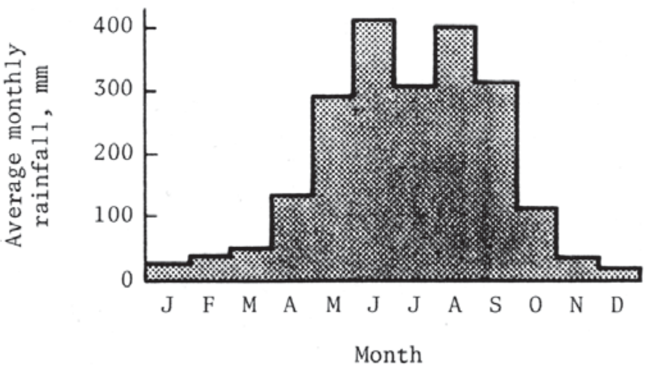


Figure 5. Distribution of average monthly rainfall

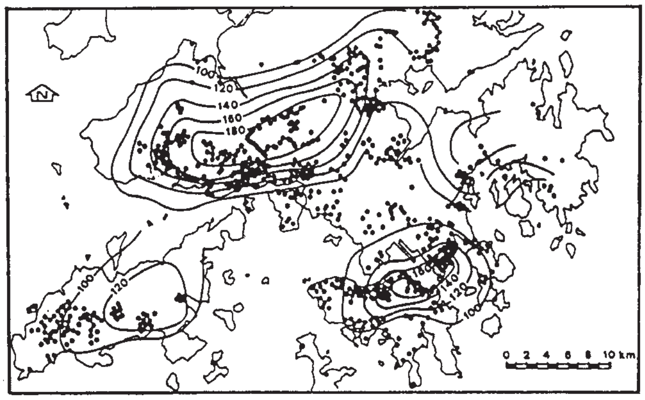


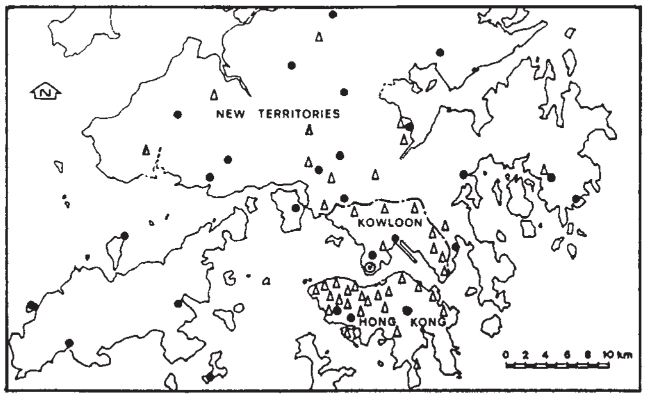
Figure 6. Landslide sites in relation to isohyets of three-hour rainfalls (mm) on 29th May 1982

landslides have in the past been responsible for large numbers of casualties. For example, in the June 1972 storm, 224 casualties resulted from the two failures that occurred at Po Shan Road on Hong Kong Island and at Sau Mau Ping in Kowloon. The vast majority of the people who were permanently evacuated from their homes as a result of rainstorms were people who occupied temporary squatter dwellings on unformed sites.

The geographical variation of rainfall over the Territory during any rainstorm event is considerable and is largely attributable to the effects of topography. Common features of Hong Kong rainstorms are that the highest rainfalls occur near the tops of large hills, and that the rainfall isohyets tend to follow the ground elevation contour lines (Bell & Chin, 1968). These features are illustrated in Figure 6, which shows the contours of two separate three-hour rainfalls during the May 1982 rainstorm.

Rainfall statistics for Hong Kong are based on one 'principal' raingauge situated at the Royal Observatory on the Kowloon peninsula (Figure 7). The rainfall records at this one location are not necessarily representative of the rainfall conditions throughout the Territory, particularly for intense local storms, but the measurements made there have been used for many years to represent the 'average' rainfall situation throughout Hong Kong. Hourly rainfall measurements have been made since 1884 at the Observatory, with the exception of the war years from 1940 to 1946, and several autographic gauges have been installed to give a wider geographical coverage of detailed rainfall measurements. A much improved system of raingauges, however, has come into use since 1978 to provide information for the Geotechnical Control Office's landslide correlation programme. Forty-two automatic gauges are now in operation. These transmit rainfall measurements continuously through telephone lines to a central micro-computer which prints out the rainfalls at five-minute intervals. The locations of all the existing continuously recording raingauges in Hong Kong are shown in Figure 7.

The existence of an automatic raingauge system has enabled the Geotechnical Control Office to gather valuable data on rainfall distribution and intensity over the past few years. In particular, detailed information was obtained on the two major rainstorms that occurred in May and August of 1982, which resulted in over 1 500 landslides (observed from aerial photographs) with a loss of 27 lives, and on the rainstorm of June 1983, which caused more than 150 landslides. These rainstorms ranked third, fifth and sixth of the last twenty years' rainstorm events in terms of 24-hour rainfall (Table 1).



(⊙ Observatory : ● autographic : Δ automatic)

Figure 7. Locations of continuously recording raingauges

LANDSLIDE DATA

Accurate information on the number of landslides and the times at which they occur is necessary if meaningful correlations are to be made with short duration rainfall intensities. Since the establishment of the Geotechnical Control Office in 1977, a considerable amount of valuable information has been collected, particularly in respect of landslide characteristics and mechanisms (Hencher et al, 1984) and in evaluating the susceptibility of terrain to landslides (Brand et al, 1982). Information on precise times of failure, however, are much more difficult to obtain. Although staff of the Geotechnical Control Office are available to deal with landslide incidents as they occur, there is often a delay of several hours between an incident occurring and an engineer being called out to inspect the failure; landslides in rural areas are often not inspected for several days. Accurate information on the time of an incident is therefore often not reliable from this source.

In collecting data for its landslide correlation studies, the Geotechnical Control Office has found the Fire Services Department to be an extremely reliable source of information on occurrence of landslides in Hong Kong over the past twenty years. Although they are involved with only a small proportion of the total number of landslides that occur, these comprise all the more serious incidents, and their excellent records can be considered to be representative of the landslide events in Hong Kong as a whole. Their data which relate to times of call-out are particularly good, and the fact that they are usually called to a serious incident immediately after its occurrence enables the time of failure to be fixed fairly accurately.

The correlation studies which form the subject of this Paper were therefore undertaken largely on the basis of Fire Services data on the times of occurrence of landslides, together with the rainfall data from the principal Observatory raingauge and the GCO's 42 automatic gauges.

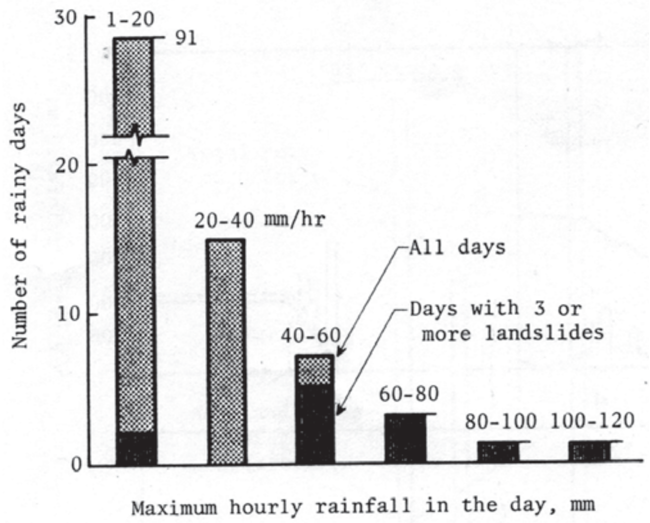


Figure 8. Distribution of rainy days and days with three or more landslides during 1982, against maximum hourly rainfall anywhere

THE RAINSTORMS OF 1982 AND 1983

With 3 248 mm of rain, 1982 was the wettest year in Hong Kong since records began in 1884. Figure 8 shows the distribution of all rainy days throughout the year and of days with three or more landslides, against the maximum hourly rainfall for each day measured at any location. It can be seen that most of the rainy days

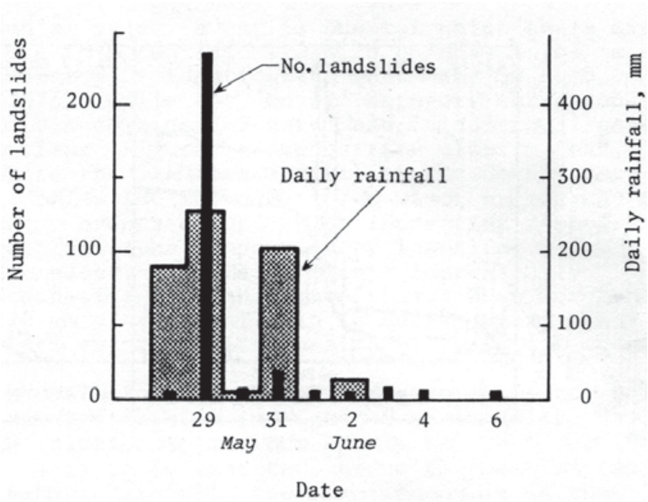


Figure 10. Time distribution of rainfall and landslides for May 1982 rainstorm event

had maximum hourly rainfalls of less than 20 mm and that no landslides occurred on most of these occasions. In contrast, landslides usually occurred on the few days on which the maximum hourly rainfall was in excess of 40 mm, and these were concentrated in the vicinity of the area that experienced the maximum rainfall.

The two major rainstorm events of May and August 1982 are summarised in Table 1. The locations of landslides that occurred during the May rainstorm are included in Figure 6. There is some measure of correlation between the three-hour maximum rainfall and the locations of landslides, but the locations of landslides in man-made slopes are dominated by the locations of the urban areas.

For the two 1982 rainstorms and the June 1983 rainstorm, which was more localised in character, Figure 9 shows the hourly and cumulative rainfall at the Observatory and at the location of measured maximum rainfall in each case, compared with the occurrence of landslides as recorded by the Fire Services Department. In all these cases, the pattern of cumulative rainfall measured at the Observatory is quite similar to that measured at the location of maximum rainfall, although it is inevitably slightly

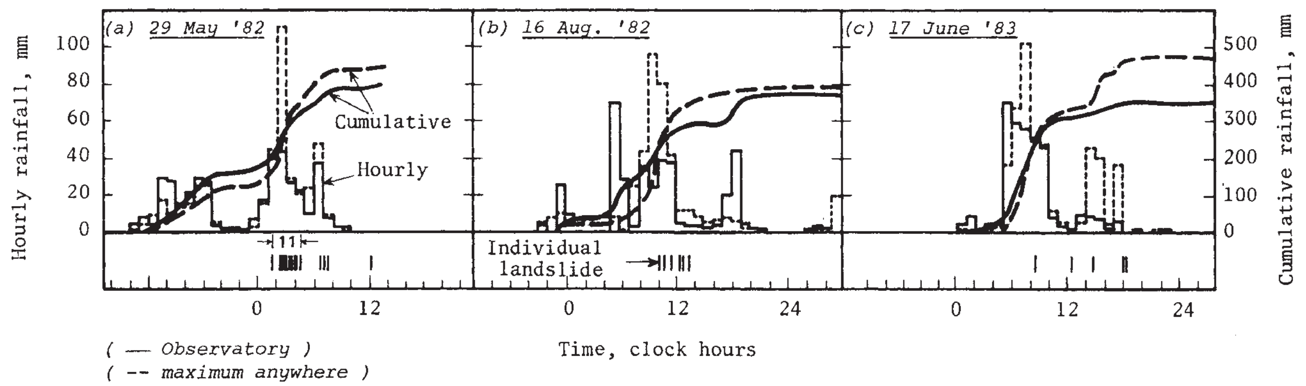


Figure 9. Times of landslide reports in relation to hourly and cumulative rainfalls for three rainfall events

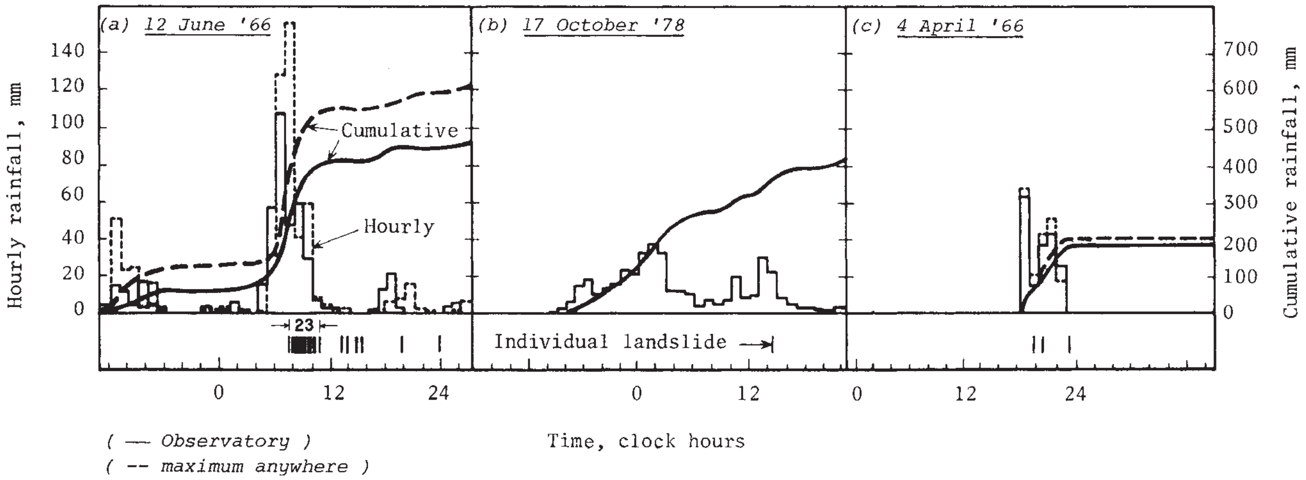


Figure 11. Times of landslide reports in relation to hourly and cumulative rainfalls for three rainstorm events

lower. In contrast, the *hourly* maximum rainfalls are dramatically higher than the corresponding ones measured at the Observatory. Landslide timings for the three rainstorms show very good correlations with hourly maximum rainfalls, which suggests that high intensity rainfall of short duration is a major triggering factor for landslides.

For the May 1982 rainstorm, Figure 10 shows the daily rainfalls at the Observatory for the event, together with the occurrence of all landslides for which the dates of failure are known. This figure shows that the large majority of landslides occurred on the 29th May, the day of the heaviest rainfall. The few failures that occurred up to a week later were probably caused by delayed groundwater build up.

RAINSTORM EVENTS FROM 1963 TO 1982

From an examination of the detailed information available for the 1982 and 1983 major rainstorms, it would appear that a direct correlation between landslides and short-period rainfall intensity exists. In order to provide more confirmatory evidence for this conclusion, information from the last twenty years (1963 to 1982) was reviewed.

The rainfall figures and the Fire Services information on failure times for 1982 and 1983 can be considered to be reliable. The rainfall figures obtained from autographic gauges prior to the installation of the GCO automatic gauge system are much less satisfactory, but they nevertheless provide useful information.

Figure 11 shows rainfall and Fire Services landslide information for two storms in 1966 and one in 1978. In June 1966, the heaviest rainfall in memory fell on Hong Kong Island, and the highest hourly rainfall to-date was recorded at the Observatory. Widespread landslides and flooding occurred. The plot for this event (Figure 11(a)) shows the direct relationship between the time of landslide occurrence and the peak hourly rainfall intensity, which is typical for many other events in the twenty-year period. It also shows the similarity between the plot of cumulative rainfall at the Observatory and that at the maximum rainfall location, and the wide divergence between hourly maximum values.

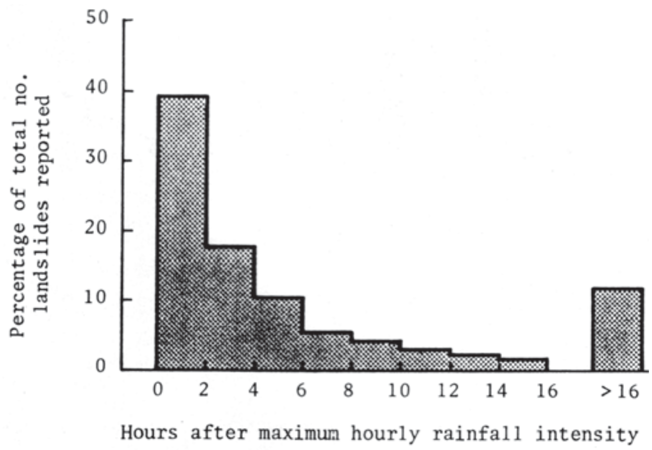


Figure 12. Times between maximum rainfall intensity and landslide reports for period 1963 to 1982

Figure 11(b) deals with the October 1978 rainstorm. Although the 24-hour rainfall of 380 mm was the fourth highest for the twenty-year period, only one landslide and one casualty were reported for this event, for which the maximum hourly rainfall was only 38 mm. In contrast, the rainstorm of April 1966 (Figure 11(c)), for which the 24-hour rainfall was only 200 mm, resulted in three landslide reports and four casualties; the maximum hourly rainfall recorded anywhere was 68 mm. These figures lend confirmation to the dependence of landslide occurrence on the short duration rainfall intensity.

For the twenty-year period from 1963 to 1982, an analysis of all the times of occurrence of landslides has been carried out. The results presented in Figure 12 show that the majority of the reported landslides occurred within four hours of peak rainfall intensities, with only 10% taking more than 16 hours to occur. This is in very good agreement with the timings of landslides for the single rainstorm event of May 1982 (Figure 10).

The dependence of landslide occurrence on hourly rainfall intensity is clearly shown in Figure 13. Throughout the twenty-year period, the number of landslides that caused casualties was very small unless the maximum hourly rainfall anywhere in the Territory approached 70 mm. Above this figure, the number of landslides with casualties increased sharply with increasing maximum hourly intensity. The actual number of casualties caused by landslides shows a similar but even more dramatic correlation with hourly intensity.

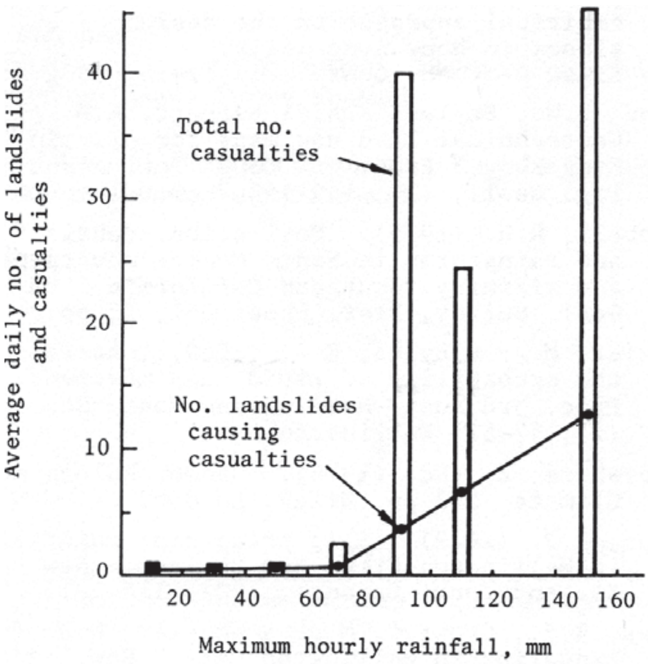


Figure 13. Landslide consequences in an average landslide day with respect to maximum hourly rainfall anywhere

EFFECT OF ANTECEDENT RAINFALL

Some previously published correlations between landslides and rainfall have taken account of the antecedent rainfall. This is justified by considerations of the soil moisture deficit and its direct relationship to shear strength. The best known correlations made on this basis are probably those by Lumb (1975) for Hong Kong, and Eyles (1979) and Crozier & Eyles (1980) for Wellington, New Zealand.

The evidence recently assembled in the Geotechnical Control Office and presented in this Paper suggests that the antecedent rainfall is in fact not a significant factor in the occurrence of major landslide events. These appear to be directly related to short duration rainfall intensity. It is common, however, for such high intensity rainfalls of short duration to occur during prolonged rainfall events. Where limited information is available on rainfall intensities and times of landslides, it is therefore not surprising that a relationship can be found to exist between antecedent rainfall and the occurrence of a large number of landslides.

It is of interest to note that the three- or four-day antecedent rainfall appears to influence the occurrence of *minor* landslide events in Hong Kong when short duration intensities do not dominate. This indicates that soil moisture deficit is certainly a factor in rain-induced landslides in soil slopes, but that its effects are secondary in situations of high intensity rainfall.

An examination of the relationship between landslides in Hong Kong and the Observatory 24-hour rainfall is fruitful. This has been done for the recently acquired data, and the results are plotted in Figure 14 on the basis of two categories of event: a 'minor' event is one for which there are less than ten recorded landslides in one day (as reported in newspapers), and a 'major' event is one for which there are more than ten landslides in one day. The 'minor' category is identical to that used by Lumb (1975), while the 'major' category corresponds to his combined 'severe' and 'disastrous' categories. Figure 14 demonstrate clearly that, where the 24-hour rainfall at the Observatory is below 100 mm, only a few minor events and no major events occur. With increasing 24-hour rainfall, the proportion of landslide days increases, with major events increasingly dominating at higher rainfalls. When more than 270 mm of rain falls in 24 hours, every rainstorm event results in a major landslide event.

The relationship shown in Figure 14 is not unlike the distribution in Figure 6 of landslide days in relation to maximum hourly rainfall for 1982. This is to be expected, since the heavier the 24-hour rainfall, the more likely it is that it will include a short duration rainfall of high intensity. The main importance of the correlation between landslides and the 24-hour rainfall, however, is its usefulness as a landslide warning criterion, since the accumulation of rainfall to approach a 'trigger' value can be sensibly anticipated a few hours in advance, whereas the short duration intensity cannot possibly be predicted in advance with any precision. The use of the 24-hour rainfall also has the advantage that measurements from the Observatory gauge alone can be used to represent the situation throughout the whole Territory.

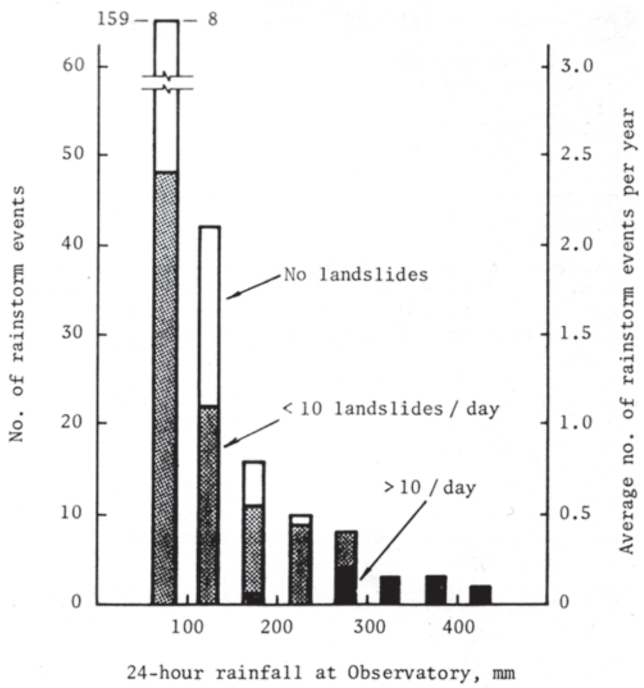


Figure 14. Relationship between Observatory 24-hour rainfall and landslide events for all rainstorm events from 1963 to 1982 for which 24-hour rainfall exceeded 50 mm

CONCLUSIONS

A study of detailed landslide information and rainstorm data for the last twenty years in Hong Kong has led to the following conclusions:

(i) The large majority of landslides are induced by localised short duration rainfalls of high intensity, and these landslides take place at about the same time as the peak hourly rainfall.

(ii) Antecedent rainfall is not a major factor in landslide occurrence, except in cases of minor landslide events which take place under relatively low intensity rainfalls of short duration. In these circumstances, only a few days antecedent rainfall appears to be significant.

(iii) A rainfall intensity at about 70 mm/hour appears to be the threshold value above which landslides occur. The number of landslides and the severity of the consequences increase dramatically as the hourly intensity increases above this level.

(iv) The 24-hour rainfall usually reflects short duration rainfalls of high intensity, and can therefore be used as an indicator of the likelihood of landslides. A 24-hour rainfall of less than 100 mm is very unlikely to result in a major landslide event; this fact could form the basis of a satisfactory landslide warning system.

These conclusions are thought to be of significance not only for Hong Kong but for other parts of the world which suffer from rain-induced landslides.

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REFERENCES

Allen, P.M. & Stephens, E.A. (1971). Report on the Geological Survey of Hong Kong, 116 pp. plus 2 maps. Hong Kong Government Press, Hong Kong.

Barata, F.E. (1969). Landslides in the tropical region of Rio de Janeiro. Proc. 7th ICSMFE, (2), 507-516, Mexico City.

Bell, G.J. & Chin, P.C. (1968). The Probable Maximum Rainfall in Hong Kong. Royal Observatory, Hong Kong, Technical Memoir no. 10, 154 pp.

Brand, E.W. (1982). Analysis and design in residual soils. Proc. ASCE Spec. Conf. Engineering and Construction in Tropical and Residual Soils, 89-143, Honolulu.

Brand, E.W. (1984). Landslides in Southeast Asia: a state-of-the-art report. Proc. 4th Int. Symp. Landslides, (in press), Toronto.

Brand, E.W. & Hudson, R.R. (1982). CHASE - An empirical approach to the design of cut slopes in Hong Kong soils. Proc. 7th S.E. Asian Geotech. Conf., (1), 1-16, Hong Kong.

Brand, E.W., Styles, K.A. & Burnett, A.D. (1982). Geotechnical land use maps for planning in Hong Kong. Proc. 4th Cong. Int. Assoc. Eng. Geol., (1), 145-153, New Delhi.

Campbell, R.H. (1975). Soil slips, debris flows, and rainstorms in Santa Monica mountains and vicinity, Southern California. US Geol. Survey, Prof. Paper 851, 55 pp.

Crozier, M.J. & Eyles, R.J. (1980). Assessing the probability of rapid mass movement. Proc. 3rd Aust. -New Zealand Conf. Geomech., (2), 47-51, Wellington.

Derbyshire, E. (Ed.)(1976). Geomorphology and Climate, 512 pp. Wiley, London.

Eyles, R.J. (1979). Slip triggering rainfalls in Wellington City, New Zealand. New Zealand Jour. Science, (22), 117-121.

Eyles, R.J., Crozier, M.J. & Wheeler, R.H. (1978). Landslips in Wellington City. New Zealand Geographer, (34), 2, 58-74.

Fukuoka, M. (1980). Landslides associated with rainfall. Geotechnical Eng., (11), 1-29.

Geotechnical Control Office (1984). Geotechnical Manual for Slopes (2nd edition). Hong Kong Government Printer, Hong Kong.

Guidicini, G. & Iwasa, O.Y. (1977). Tentative correlation between rainfall and landslides in a humid tropical environment. Bull. Int. Assoc. Eng. Geol., no. 16, 13-20.

Hencher, S.R., Massey, J.B. & Brand, E.W. (1984). Application of back analysis to some Hong Kong landslides. Proc. 4th Int. Symp. Landslides, (in press), Toronto.

Lumb, P. (1965). The residual soils of Hong Kong. Géotechnique, (15), 180-194.

Lumb, P. (1975). Slope Failures in Hong Kong. Qtrly Jour. Eng. Geol., (8), 31-65.

Lumb, P. (1979). Statistics of natural disasters in Hong Kong, 1884-1976. Proc. 3rd Int. Conf. Applic. Statistics & Prob. to Soil & Struc. Eng., (1), 9-22, Sydney.

Morgenstern, N.R. (1978). Mobile soil and rock flows. Geotechnical Eng., (9), 123-141.

Onodera, T., Yoshinaka, R. & Kazama, H. (1974). Slope failures caused by heavy rainfall in Japan. Proc. 2nd Int. Cong. Int. Assoc. Eng. Geol., (2), V-11.1 to V-11.10, Sao Paulo.

Rossetti, R. & Ottone, C. (1979). Esame preliminaire delle condizioni pluviometriche dell'Oltrepò Pavese e dei valori critici delle precipitazioni in relazione ai fenomeni di dissesto franoso (Preliminary analysis of rainfall in Oltrepò Pavese and the critical rainfall values as related to landslide failures). Geologia Applicata e Idrolgeologia, (14), 3, 83-99.

Ruxton, B.P. (1960). The geology of Hong Kong, Qtrly. Jour. Eng. Geol., (115), 233-260 (plus 2 plates & 1 map).

Ruxton, B.P. & Berry, L. (1957). Weathering of granite and associated erosional features in Hong Kong. Bull. Geol. Soc. America, (68), 1263-1291 (plus 1 plate).