Slope Movement and Failure: Evidence from Field Observations of Landslides Associated with Hillside Cuttings in Saprolites in Hong Kong

A. W. Malone
The University of Hong Kong
(formerly Geotechnical Engineering Office, Civil Engineering Department, Hong Kong)

Abstract: This presentation summarizes the results of research into slope movement and failure associated with hillside cuttings in igneous rock saprolites in Hong Kong. Evidence is presented of slope movement in twenty-three case histories. The classification of stages of slope movement suggested by Leroueil et al (1996) is able to accommodate the field evidence, with modifications. The landslides are separated into two main groups based on geometry and the velocity of post-main failure movement. The steep-shallow landslides move extremely rapidly after main failure and travel many metres or tens of metres until arrested whereas the deep landslides generally move slowly, displacing by about 1 to 3 m before coming to rest, and show evidence of pre-main failure movement. Such behaviour may be explained in terms of the mechanical properties of the saprolite materials and their discontinuities.

1 INTRODUCTION

Rain-induced landsliding is commonplace in Hong Kong's hillside regolith in the summer months and risk levels are high. The Government therefore operates a slope safety system, one component of which is a programme of investigations of the larger landslides. The research summarised here used data from the archived reports of some of these landslide investigations to study slope movements associated with cuttings and to examine evidence linking failures and the presence of adverse hydrological and geological features.

Hong Kong's hillside saprolites, sandy and silty soils, are the product of the weathering of Middle Jurassic to Early Cretaceous granites and chemically similar ash flows, along with dyke rocks. They comprise material in the Grades IV and V condition (Table 1, Geotechnical Control Office 1988) with blocks of less weathered rock. Rock joints, primary volcanic fabrics, dykes, etc are preserved. Grade VI material is generally thin or absent but a surface colluvial cover is quite common. Natural slopes are steep (25 to 35° plus) and heavily developed in places to accommodate Hong Kong's population of 6.6 million within its 1100 square km land area.

Between 80 and 800 failures in cuts and fills are reported annually to the Geotechnical Engineering Office, the number depending on rainfall. Some 5 to 10% are greater in volume than 50 cu m and these are classed locally as 'major' failures.

The reports of the investigations of twenty-three major failures associated with cuttings in igneous rock saprolites were recently reviewed with respect to slope movements and adverse features. These are the known cases where a detailed study of the landslide was undertaken, conclusions reached regarding causes of failure and an adequately detailed geotechnical report is available. The locational names of the landslides used in the reports and publications are given in Appendix 1. For 16 cases information additional to that given in the reports and publications was obtained from members of the investigation teams. Eleven of the studies were carried out in the 1990s, eleven in the 1980s and one in 1970 and 1971. Except for one case, these twenty-three failures are rain-induced translational or compound slides in saprolite. One involved only pre-main failure movements.

The twenty-two cases from the years 1982 to 1997 constitute a 7% sample of the 320 reported major failures in slopes classified in the government inventory as 'soil' or 'soil/rock' cuttings. Failures in 'rock' cuttings are not included in this number. Around 24,000 such features of height greater than 3m have been registered. The 7% sample includes nearly all of the large volume cut failures (> 1500 cu m) reported between 1982 and 1997 but it significantly under-represents the major landslips of lesser volume.

With regard to lithology and weathering at the twenty-three sites, 14 are in weathered granite (typically silty sand) and 9 are in weathered tuff (normally silt). According to information in the reports, the rupture surface occurred in saprolite in all cases, and passed through surficial colluvium in several cases. The saprolite material through which the rupture surface passed is described as weathering grade IV (4 cases, two granite two tuff), grades IV and V (9 cases, eight granite one tuff), grade V (9 cases, three granite six tuff) and grade VI (1 case, granite). Seven of the thirteen large volume landslides are in granite and six are in tuff.

Table 1. Material decomposition classification

Descriptive Term	Grade Symbol	General Characteristics for Granitic & Volcanic Rocks & Other Rocks of Equivalent Strength in the Fresh State
Residual Soil	VI	Original rock texture completely destroyed Can be crumbled by hand and finger pressure into constituent grains
Completely Decomposed	V	Original rock texture preserved Can be crumbled by hand and finger pressure into constituent grains Easily indented by point of geological pick Slakes when immersed in water Completely discoloured compared with fresh rock
Highly Decomposed	IV	Can be broken by hand into smaller pieces Makes a dull sound when struck by geological hammer Not easily indented by point of geological pick Does not slake when immersed in water Completely discoloured compared with fresh rock
Moderately Decomposed	III	Cannot usually be broken by hand; easily broken by geological hammer Makes a dull or slight ringing sound when struck by geological hammer Completely stained throughout
Slightly Decomposed	II	Not broken easily by geological hammer Makes a ringing sound when struck by geological hammer Fresh rock colours generally retained but stained near joint surfaces
Fresh	I	Not broken easily by geological hammer Makes a ringing sound when struck by geological hammer No visible signs of decomposition (i.e. no discolouration)

2 DEFINITIONS

The definitions used here are given below. They are not intended for wider usage.

Main failure stage : the stage at which a continuous shear zone or surface forms through the entire saprolite mass, recognised in these cases by the formation of a scarp around the head, surficial deformation on the main body and movement at the toe.

Ductile landslide : a landslide involving the small integral movement of a body of ground along a continuous shear zone after main failure.

Detachment : a landslide involving the extremely rapid movement of a body of ground along a continuous shear zone after main failure; a ductile landslide may yield detachments, either steep-shallow detachments from the cut face or deeper-seated detachments partly along the shear zone.

Toe-crown angle : the angle of inclination to the horizontal of a line between the daylighting points of the shear zone at the toe and the crown.

'Depth' : the maximum distance between the ground surface before main failure and the shear zone, measured normal to the toe-crown line.

Pre-main failure movements : movements occurring before the main failure stage except those occurring at the time of cutting or before.

Post-main failure movements : movements occurring after main failure until motion ceases.

Reactivation: renewed movement of a ductile landslide along the shear zone.

3 GEOMETRY

The landslides were classified as either ductile landslides or detachments based on the evidence of movement after main failure (Appendix 2). Ten of the twenty-three cases are ductile landslides (including one questionable case referred to below) twelve are detachments and the other case involved only pre-main failure movements (Cheung Sha Fresh Water Service Reservoir). Five of the ductile landslides produced a total of eight major detachments. The classification of the Fei Tsui Road case as a ductile landslide based, as it is, only on the evidence in Appendix 3, is questionable.

The ductile landslides are all large compared to the detachments in the sample of 23 and detachments generally in Hong Kong. The dimensions of a typical ductile landslide may be 30 m x 40 m x 8 m (total length x width of displaced mass x 'depth'). Their volume ranges from some 2000 cu m to greater than 100,000 cu m. In contrast, the twelve detachments range in volume generally from 70 cu m to 1500 cu m, with one case 3-4000 cu m (Ching Cheung Road, 1982). Large volume landslides make up a small proportion of the total number of major landslides associated with cuttings in saprolite. In the years 1992 to 1996 fewer than 4% of major landslips in saprolite cuts were of greater volume than 2000 cu m.

The toe-crown angles and 'depths' of the landslides measured at the vertical section chosen by the investigator for stability analysis are plotted in Figure 1. Only 17 detachment points appear on the plot because one point (54°, 1.7 m) represents three detachments at Tin Wan Hill Road in 1985 and the geometrical parameters for the detachment 'near KCR Fo Tan Station' cannot be determined from information available.

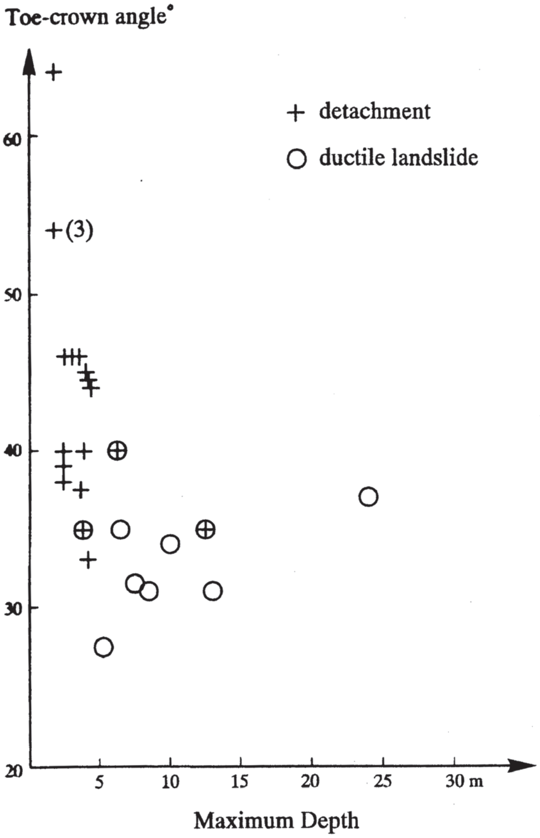

Figure 1. Geometry of the landslides

The detachments and ductile landslides are geometrically distinct save for three detachments plotted coincident with ductile landslides. These are detachments occurring partly in previously sheared ground (Island Road Government School, Fei Tsui Road and Ching Cheung Road 1997, see Appendices 2 and 3). Excluding these three cases, the average toe-crown angles and 'depths' are 45°/2.8 m (detachments) and 33°/9.7 m (ductile landslides, including the questionable Fei Tsui Road), and the detachments are less than 5 m in 'depth' whereas the ductile landslides are greater.

In the sample of 23 cases, the steep-shallow landslides ('depth' <5 m, toe-crown angle >37.5°) moved a large distance extremely rapidly after main failure whereas generally the deep landslides (>5 m) moved a small distance after main failure before coming to rest (Fei Tsui Road is the one exception, assuming main failure occurred on 13.8.95, which is questionable). An explanatory hypothesis for such distinctive behaviour is presented later in the paper.

4 EVIDENCE OF MOVEMENT

The reports of the investigations of the twenty-three landslides and the associated material provided by the investigators contain a striking amount of information about slope movement. A brief summary of the evidence pertaining to movement at main failure and before main failure is given in Appendices 2 and 3 respectively. The stages of movement evident from these data are shown in Figure 2 which is based on the stages of slope movement suggested by Leroueil et al (1996). Two additional stages are added: 'ancient', meaning movements in the hillslope regolith of unknown age and movements during cutting. Not all of the stages are seen in every case. The types of evidence in the 23 case histories at the various stages of movement are summarised in Table 2.

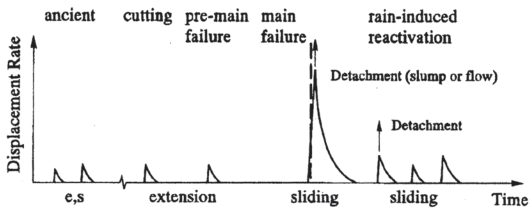

Figure 2. Data on movement in the 23 cases

Table 2. Types of evidence of movement in the 23 cases

Fabrics associated with ductile shear (S-C fabrics, Davis & Reynolds, 1996) and open joints filled by transported material (Kirk et al, 1997)	generally of unknown age
Contemporaneous observations of tension cracking and flexural topple associated with joints (Cowland & Carbray, 1988)	during cutting, pre-main failure, main failure
Scarps seen on aerial photographs taken in the past	main failure
Cracking evidently reactivated, displaced small-scale geological features and infilled tension cracks recorded by investigators after main failure	generally of unknown age
Recent scarps, tension cracks, surface disruption, deformation and cracking; eye witness evidence of detachment or gross movement	main failure, reactivation
Displacement from instrumental measurements by topographical surveying instruments and borehole inclinometers	rarely main failure, reactivation

The evidence of slope movement in the 23 cases and one other is summarised in Figure 3. Measurements of displacement with depth in a borehole inclinometer at the Pak Kong Water Treatment Works (Lam, 1995) are included. These are the only known measurements at a hillside cutting in Hong Kong of movements with depth before main failure.

It is apparent from the evidence in Figure 3 that the profiles of movement with depth before and after main failure in ductile landslides are markedly different. Before main failure, when a complete rupture surface has yet to form, the greatest movement takes place at the surface. After main failure significant movement also takes place at depth, as the landslide moves on the rupture surface.

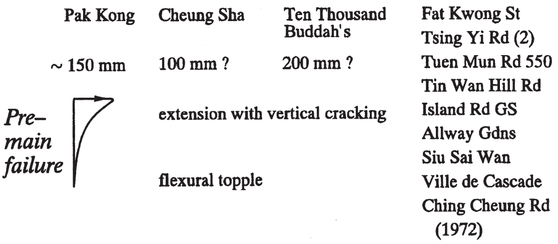

Figure 3a. Measured and estimated movements (Pre-main failure)

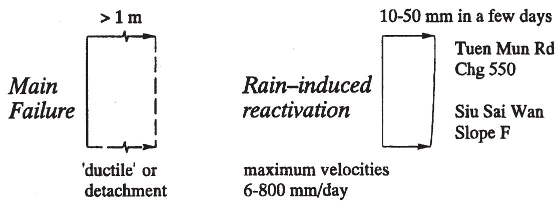

Figure 3b. Measured and estimated movements (Main failure and rain-induced reactivation)

5 MOVEMENTS BEFORE MAIN FAILURE

At seven of the ten *ductile landslides* there is evidence of movement before main failure, comprising tension cracking or flexural topple during cutting (2 cases), cracking or other visible movement pre-main failure (6 cases). The time of main failure is uncertain for the Fei Tsui Road case and evidence of movement before 13.8.95 is therefore not counted. For Tsing Yi Road (1) 1982 and Ching Cheung Road 1997 (main failure before the 1954 aerial photograph) there is no known evidence of movement before main failure.

There are no measurements of the magnitude of pre-main failure movements in any of the 10 ductile cases. At Pak Kong Water Treatment Works displacement at the surface in the upper part of the cut amounted to about 150 mm in $2^1/_2$ years. Movement occurred in two episodes following heavy rain. Displacement of the same order may be inferred from the total width of cracking at Cheung Sha Fresh Water Service Reservoir.

With regard to movements before detachment, in the scarps of two of the twelve detachments (ie not counting the detachments from ductile landslides) investigators recorded the presence of pre-existing tension cracking of unknown age (Allway Gardens and Ten Thousand Buddhas Monastery). In the latter case, the total width of the recorded infilled cracks is estimated at about 200 mm.

With regard to the 'detectability' of signs of movement before main failure, it is known that in three of the ten ductile cases cracking was noticed at the time of cutting (Siu Sai Wan, Tuen Mun Road Chainage 550, Cheung Sha Fresh Water Service Reservoir).

6 MOVEMENTS AT MAIN FAILURE AND ON RAIN-INDUCED REACTIVATION

The evidence pertaining to the nature and magnitude of movement at *main failure* for eight of the ten ductile landslides is given in Appendix 2. Maximum vertical displacement at the scarp ranges from about 1 m to 3 m. Where movements in the main body of the landslide were measured, these range up to 700 mm downslope in 5 days (middle part of a translational-rotational landslide, Siu Sai Wan, Slope F), 1.7 m downslope in 35 days (in the upper portion of a rotational slide, Tuen Mun Road Chainage 550) and 2 m out of slope in 13 days (in the lower part of a structure-controlled block slide, Fat Kwong Street). The initial period of movement at main failure may be of the order of hours or days. Velocities reduce with time and motion ceases within a period of weeks in most cases.

In seven of the ten ductile cases there is evidence of *reactivation* or *acceleration* following heavy rain. Velocities of movement at the surface range from 6 mm to 800 mm per day. In two cases inclinometers show significant movements taking place at depth during rain-induced reactivation, with velocities between 10 and 50 mm in a period of a few days (Tuen Mun Road, Chainage 550 and Siu Sai Wan, Slope F). Reactivation was accompanied by major detachment in three cases (not counting Fei Tsui Road). In one case the process appears to have stalled at main failure because subsequent heavy rain did not cause reactivation despite significant increase in water pressure (Tsing Yi (2)).

In none of the ten cases is there evidence allowing examination of the course of landslide movements over a period of years because in nearly all of these cases remedial works were completed before the next wet season.

7 DISCUSSION OF THE EVIDENCE OF MOVEMENT

Only two of the above findings will be discussed further in this paper. First, the finding that at main failure steep-shallow landslides moved extremely rapidly a distance of the order of metres or tens of metres whereas the deep landslides moved one to three metres before coming to rest. Fei Tsui Road is the one exception if main failure occurred in 1995. Second, the finding that ductile landslides generally show evidence of movement before main failure whereas such evidence has not been generally recorded for the detachments.

The velocity of movement of a frictional body sliding on an inclined plane is dependent upon the available kinetic energy per unit area of slip surface. For slip surfaces which drop in strength after strength reaches a peak there will be surplus kinetic energy, the amount depending on the magnitude and the sharpness of the drop in strength and the quantity of work done internally.

Whether the actual materials and joints along the rupture surfaces in the 23 cases would have exhibited a drop in strength under field conditions is unknown, as the particular testing required to establish this was not conducted. The amount of published data from high quality testing of saprolites in Hong Kong is small. Some specimens exhibit a strain softening response in direct shear and triaxial compression and some do not. The most complete published set of relevant data are from 250 direct shear tests on Grade IV and V decomposed granites at different stress levels reported by Ebuk et al (1990). In these tests the only materials which did not exhibit some degree of strain softening were Grade V granites tested at high stress. There is no comparable published data set from triaxial compression testing of Grade IV and V granites and tuffs.

If it is assumed that the slip surfaces of the 23 cases did exhibit strain softening then it follows that progressive failure would occur (Bishop, 1967). Thus, as the cuttings were constructed and as the slopes experienced seasonal rain-induced stress changes then as Bishop describes 'the shear stresses along the potential rupture surface would rise in a non-uniform manner. If locally .... the ratio of shear stress to effective normal stress ... reaches a limiting value, local failure will result ....'. Further increase in pore pressure '.... will lead to a progressive extension of the zone of failure along the potential slip surface, while within this zone the shearing resistance will commence to drop from its peak to its ultimate or residual state. The state of limiting equilibrium is reached when failure has just extended to the whole of the slip surface and in this state the shearing resistance may be expected to vary from the peak value at the points failing last to the residual value, in the limit, at others.'

Vaughan (1995 Figure 49) illustrates the progressive development of the rupture surface in finite element modelling of delayed failure of cuttings in stiff plastic clay. In his case progressive failure resulted from slow swelling and pore pressure equilibration, whereas in the present case the cause is presumed to be seasonal cyclic stress changes.

The *ductile landslides* exhibit evidence of movement prior to main failure, which may be the product of progressive development of the rupture surface. Their movement immediately after main failure is consistent with non-energetic motion on a rupture surface which is only mildly strain-softening i.e. one which has suffered non-uniform strength drop by the process of progressive failure. The suppression of strain softening behaviour in the weaker materials at higher stresses, as seen by Ebuk et al (1990), may be a contributory factor to non-energetic motion, or even a plausible alternative hypothesis.

The *detachments* move energetically and generally show no very obvious signs of prior movement, at least not on the scale and to the same extent as do the ductile landslides. Eye witness evidence (not reported here) suggests that sliding motion precedes disintegration hence a sliding model is appropriate. It seems plausible that the greater part of the rupture surface forms during the storm which triggers the failure. Rupture surfaces are shallow hence any suppression of strain softening behaviour is less likely to occur than is the case for the deeper ductile landslides. The rupture surface will form at peak strength and the failure will be energetic.

The above hypothesis relies on assumptions which remain to be tested, especially the assumption of strain softening behaviour. Let us examine some alternative hypothesis.

The rupture surfaces of the detachments are more steeply inclined than those of the ductile landslides, on average by about 12°, thus if the rupture surfaces of both kinds of landslide were to suffer a sharp and substantial post-peak drop in strength the difference in inclination might be reflected in different velocities of motion. But in this situation both kinds of landslide would travel at high speed and the ductile landslides do not. The difference in inclination alone does not therefore explain the findings.

Hypothetical scenarios have been sought in which displacement rate effects (influence of fast rates of displacement on the residual strength of soil, Tika, et al, 1996) might alternatively explain the findings referred to in the first paragraph of this section. For example, there might conceivably be systematic differences in site characteristics producing reduced strength (negative rate effect) on rupture zones of detachments and increased strength (positive rate effect) on rupture zones of ductile landslides sites. From the reported evidence there are no such systematic differences in lithology, degree of weathering or in the prevalence of kaolin on joints forming part of the rupture zone. Moreover, ductile landslides are capable of yielding steep-shallow detachments.

However the water pressures at main failure are, from field evidence and from the limit analyses, significantly higher for ductile landslides than for detachments and there is evidence of a slower rise in water pressures before main failure for ductile landslides than for detachments (Malone, in preparation). But neither of these differences seem very likely to produce rate effects which explain the findings. The kinematic energy/strain softening hypothesis is more plausible than a rate effects hypothesis.

8 CONCLUSIONS

From a study of 23 failures associated with cuttings in igneous rock saprolites in Hong Kong it is concluded that the steep-shallow landslides in the sample moved a relatively large distance at high speed after main failure whereas in general the deeper landslides, those of much greater volume, moved by a small amount and then came to rest. The latter landslides exhibited pre-main failure movement but generally there is no evidence that the steep-shallow landslides moved significantly before main failure.

Such distinctive behaviour may be explained in terms of the strain softening characteristics of saprolite material and joints on the rupture surface and by the phenomenon of progressive failure.

ACKNOWLEDGMENTS

The data which I have used are contained in reports of landslips mainly investigated by staff of the Geotechnical Engineering Office and its consultant Halcrow Asia Partnership Ltd. I am most grateful to all of the people involved, especially Dr S.R. Hencher, for so willingly answering all of my questions relating to their studies and providing additional information from their records. The permission of the government's Director of Civil Engineering to use data from recent landslip studies not yet published is also gratefully acknowledged.

REFERENCES

Au, S.W.C. & Suen, R.Y.C. (1996). Environmental factors in triggering slope failures. Proc. 7th Int. Symp. Landslides, Senneset (ed), Balkema, Rotterdam, 611-616.

Bishop, A.W. (1967). Progressive failure with special reference to the mechanism causing it. Proc. Geot. Conf. Oslo, Norwegian Geotechnical Institute, Volume II 142-150.

Cowland, J.W. & Carbray, A.M. (1988). Three cut slope failures on relict discontinuities in saprolitic soils. Proceedings of the Second International Conference on Geomechanics in Tropical Soils, Singapore, vol. 1, pp 253-258.

Davis, G.H. & Reynolds, S.J. (1996). Structural Geology of Rocks and Regions, John Wiley.

Geotechnical Control Office (1988). Guide to Rock and Soil Descriptions (Geoguide 3). Geotechnical Control Office, Hong Kong, 189p.

Irfan, T.Y. (1994). Mechanism of creep in a volcanic saprolite. Quarterly Journal of Engineering Geology, vol. 27, 211-230.

Kirk, P.A., Campbell, S.D.G., Fletcher, C.J.N. & Merriman, R.J. (1997). The significance of primary volcanic fabrics and clay distribution in landslides in Hong Kong. J. Geological Society London Vol. 154, 1009-1019.

Lam, K.C. Stability of Slopes in Residual Soils, MSc Thesis, Imperial College, London, 1995.

Leroueil, S., Vaunat, J., Picarelli, L., Locat, J., Lee, H. & Faure, R. (1996). Geotechnical Characterisation of Slope Movements. Proc. 7th Int. Symp. Landslides, Senneset (ed), Balkema, Rotterdam.

O'Rorke, G.B. (1972). A cutting failure in Hong Kong granite. Proc. 3rd Southeast Asian Conf Soil Engineering, Hong Kong 161-169 (Discussion 398-399).

Tika, T.E., Vaughan, P.R. & Lemnos, L.J. (1996). Fast shearing of pre-existing shear zones in soil. Geotechnique, 46, No.2, 197-233.

Vaughan, P.R. (1994). Thirty-fourth Rankine Lecture : Assumption, prediction and reality in geotechnical engineering. Geotechnique, 44, No. 4, 573-609.

Appendix 1 Locational names and volumes (cu m) of the 23 cases

Fat Kwong Street	1970	15 000
Chai Wan Road	1982	1000
Tuen Mun Road Chg. 6750	1982	3-400
Tsing Yi Road (1)	1982	10 000
Junk Bay Road	1982	1300
Tsing Yi Road (2)	1982	3000
Ching Cheung Road	1982	3-4000
Tuen Mun Road Chg. 550	1983	100 000
Tin Wan Hill Road	1983	19 200
Cho Yiu Estate		1200
Cheung Sha Fresh Water Service Reservoir		2000
Island Road Govt. School	1988	3800
Siu Sai Wan (F)	1992	1500
Allway Gardens	1993	200-250
Castle Peak Road	1994	700
Fei Tsui Road	1995	14 000
Kau Wa Keng	1997	360
No. 7 Keng Hau Road	1997	150

Ten Thousand Buddhas Monastery	1997	1500
Near KCR Fo Tan Station	1997	100
Ville de Cascade	1997	20 000
Bayview Gardens	1997	70
Ching Cheung Road	1997	5200

Appendix 2 Evidence in the 10 of the 23 cases classified as 'ductile landslides' pertaining to main failure

Fat Kwong St. (19.9.70)
Scarp few feet high seen around head and main body. Movement in lower part of main body measured from 22 September, 6 feet horizontal and 1.5 feet vertical in 13 days; shallow detachment from face on main body on 19 September (O'Rorke, 1972).

Tsing Yi Rd. (1) (30.6.82, first seen)
Scarp 3 m high around head and main body recorded on 12 July. Heaving and distortion of drainage channel at toe. On surface of main body 1 m downslope movement with distortion of surface channels and rotation of corestones (SPR 9/83).

Tsing Yi Rd. (2) (21.8.82, first seen)
Scarp to 1 m high seen around head and main body. At toe distressed stone pitching and possible crushing of soil on relict joint. Movement on surface of main body 0-3 m vertical, up to 0.75 m horizontal (SPR 10/83, S R Hencher pers.com. 1998).

Tuen Mun Rd Chg. 550 (early Sept. 1983)
Scarp to 0.4 m high 23.9.83, 1.8 m high 5.11.83, seen around head and main body. Minor distortion of surface channel at toe. In lower part of main body surface scarps to 1 m high (flexural topple?) developed by December. Downslope movement in upper part of main body 1.7 m in 35 days (SPR 2/84).

Tin Wan Hill Rd. (12.10.83, first seen)
Scarp to 2 m high seen around head and right flank main body. At toe movement over 45 m length, some spalling of material. On surface of main body severe distress with major cracks transecting channels and in chunam (SPR 3/84).

Island Rd. Govt. School (28.6.88)
Scarp 1 m high 17 m long at head. Several other scarps and tension cracks (SPR 4/89).

Siu Sai Wan (16.4.92)
Scarp to 2.5 m high seen around head and main body. Shotcrete buckled/warped at toe. Extensive deformation of surface of main body. Downslope movement in main body 700 mm in 5 days (SPR 3/93).

Fei Tsui Rd. (if main failure earlier than 13.8.95)
Details in Appendix 3. Evidence of ductile shear displacement (top down-slip) seen in undetached portion of shear surface at right flank scarp. About 30 m away to the west evidence of down-slip movement 100-150 mm at a point under rupture surface beneath lower left main body (pers.com. Kirk 1998).

Ville de Cascade (3.7.97, first seen)
Up to 1 m vertical movement at scarp, 0.5 m horizontal. Scarp seen around head and left flank (right flank masked by remedial shotcrete). At toe bulging and distress over 30 m length. On main body surface channels displaced 200 mm. (draft LSR 16/97, Issue 1, Rev A).

Ching Cheung Rd (7.7.97)
Main failure appears to have occurred between 1949 and 1954. Scarp to 2 m high visible on 1954 and 1963 air photos. PWD Drawing No. RK 1410/1C indicates scarp several metres in height in 1964. Main perimeter crack seen in 1997 coincides with 1954 scarp in left flank. (Report on the Landslide, Halcrow Asia Partnership for GEO, February 1998, Hencher pers.com. 1998).

Note: SPR means GEO Special Projects Report.

Appendix 3 Evidence in 10 of the 23 cases pertaining to movements before main failure

Fat Kwong St. (date of main failure 19.9.70)
'movement of some boulders had been noticed on the day before the slide .. .' O'Rorke (1972)

Tsing Yi Rd. (2) (21.8.82, first seen)
Opening up of the mass on joints before main failure, inferred from changes in piezometric response to rainfall (SPR 10/83). 'many old cracks reopened' 'pre-existing slickensides on joints' (Hencher pers.com.notebook record 1998).

Tuen Mun Rd. Chg 550 (early Sept. 1983)
Cracking (flexural topple?) due to 'stress relief' noted in cutting face during construction followed by slope failure in June 1975; slope then cut back. In 1983 villagers reported that cracks had been noted in 1978. Surface depressions visible in early 1983 air photos later found to contain soil pipes (SPR 2/84).

Tin Wan Hill Rd. (12.10.83, first seen)
Heaving of road pavement at toe some time before June 1983 (SPR 3/84).

Island Rd. Govt. School (28.6.88)
Tension cracks seen on 2 June photograph at location of crown of 28 June failure (Plate 9, SPR 4/89).
Investigator interprets fabric seen in zone of soil which later became the locus of slip as deformed fabric caused by previous creep movements (Plates 36 & 38, SPR 4/89; Fig 7, Irfan 1994).

Siu Sai Wan Slope F (16.4.92)
Signs of distress involving tension cracking in the cut face seen November 1989 during slope construction. Slope then cut back. (SPR 3/93).

Allway Gardens (27.9.93)
Two sets of pre-existing tension cracks 'may

indicate past deformation ... ' (ADR 5/94). 'Organic material coating with roots & decayed leaves was noted on the cracks. Cracks thought to be a few years' old (A.C.O. Li, pers.com. 1998).

Fei Tsui Rd. (13.8.95 or earlier)

If main failure occurred on 13.8.95:
Kaolinised infill material in taper-down open joint immediately below rupture surface (opening about 100-150 mm in down-slip direction) seen in West face of pit TT3 (age unknown). Photograph in Geological Survey records. S-C fabrics, indicating ductile shear (top down-slip) seen in clay rich layer, uphill extension of rupture surface, in detached portion of scarp in right flank (age unknown). No evidence of movement of block of ground above during failure 13.8.95 although ground carefully inspected (Kirk, pers.com. 1998). Clay infill to vertical fracture above rupture surface in east face of trial pit near scarp at right flank (TTl?) indicating past movement (Hencher pers. com notebook record 1998). If main failure earlier than 13.8.95; no evidence of movements before main failure.

Ten Thousand Buddhas Monastery (2.7.97)

Open and infilled taper-down sub-vertical tension cracks in scarp at crown and right flank. 'Thought to be indicative of minor local slope movement at some time in the past'. Report on the Landslide, Halcrow Asia Partnership Ltd for GEO, March 1998.

Ville de Cascade (3.7.97, first seen)

' ... sub-vertical open relict joint about 80 mm wide (Plate 8). Displacement of a quartz vein across the open joint indicated about 200 mm vertical displacement. There was no discernible trace of corresponding movement in the overlying fill indicating that movement on the joint is likely to predate placement of the fill ...' (draft LSR 16/97 Issue 1 Rev A).