REPORT ON THE FEI TSUI ROAD LANDSLIDE OF 13 AUGUST 1995

Volume 1

INDEPENDENT REVIEW OF THE INVESTIGATION BY THE GEOTECHNICAL ENGINEERING OFFICE

Sir John Knill
Berkshire, the United Kingdom

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This Report is presented in two volumes. Volume 1 contains the independent findings of Sir John Knill on the Fei Tsui Road landslide of August 1995 and the lessons to be learnt from it. Volume 2, prepared by the Geotechnical Engineering Office of the Civil Engineering Department, presents the detailed findings of the landslide investigation. The contents of Volume 2 have been reviewed and agreed by Sir John Knill who relies on them in his own assessment given in Volume 1.

Requests for additional copies of this Report should be sent to :

Chief Geotechnical Engineer/Special Projects,
Geotechnical Engineering Office,
Civil Engineering Department,
Civil Engineering Building,
101 Princess Margaret Road,
Homantin, Kowloon,
Hong Kong.

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1. INTRODUCTION

Intense rainfall occurred in Hong Kong on 12 and 13 August 1995 in the wake of Typhoon Helen; there were reports of over 120 landslides. One of these landslides, at Fei Tsui Road in Chai Wan, caused the burial of the road in slide debris. There was one fatality and one person was injured.

The Geotechnical Engineering Office (GEO) of the Civil Engineering Department commenced an investigation of the landslide on the morning of 13 August 1995. The results of this investigation are reported in an accompanying document (GEO, 1996).

It was decided to have an independent technical review of the GEO investigation, which the writer was invited to carry out, reporting to the Government of Hong Kong. Three visits were made for this purpose over the periods 5-8 September, 31 October-3 November and 27 November-1 December 1995. During these visits the site was inspected twice, and discussions were held with GEO regarding the investigation programme and the results as progressively achieved. An advanced draft of the GEO report was reviewed directly with the GEO.

2. DESCRIPTION OF LANDSLIDE

The landslide took place in a cut slope excavated into the northern side of a spur of volcanic rocks which extends in a east-north-east direction down from the flanks of Mt Collinson. The site formation was carried out between 1972 and 1976 as part of the construction of the Hing Wah Estate Phase II development. Fei Tsui Road was built on the northern side of the slope which had a maximum height of about 27 m and an overall slope angle of about 60°. The Chai Wan Salt Water Service Reservoir which was constructed in 1959 is located on the crest of the spur immediately to the south of the cut slope. To the east of the Reservoir the top of the spur above the crest of the slope is composed of flat vegetated land which was, up to 1991, occupied by a squatter settlement. The southern flank of the spur is formed by a valley with a small stream which exits at the eastern end of Fei Tsui Road.

The slope was excavated with a narrow berm at about two thirds of its height, the upper part of the slope being chunamed at the time of construction; the lower part of the slope consists of exposed rock. The slope face at the time of the landslide was covered with vegetation. In front of the slope, and separating it from Fei Tsui Road, there is a 12 m wide strip of level ground which was fenced-off, being partly covered by grass and partly used for temporary storage of drainage equipment.

Since the excavation of the slope four small failures have taken place in 1985, 1986, 1987 and 1993. The debris from all these failures had been confined within the limits of the level ground in front of the rock face.

The landslide took place in two stages, this observation being well-documented by eye witnesses. The first failure occurred at about 0055 on 13 August at the eastern end of the eventual landslide immediately adjacent to the site of the 1993 failure. The failure involved

some tens of cubic metres of rock and, like the four previous small failures, the debris was confined to the level ground. The second, major, failure occurred about 20 minutes later cutting 40 m back into the slope and forming a scar with a maximum length of nearly 90 m long and with an average vertical depth of about 15 m. About 14,000 m^3 of debris slid out of the scar crossing the fenced-off level ground and Fei Tsui Road, entering a playground and mounding up against the side of the Chai Wan Baptist Church to a maximum depth of 6 m. The maximum extent of the debris mound from the toe of the slope was 33 m, and the mound had a length of just over 90 m along Fei Tsui Road indicating that little lateral spreading occurred.

The general appearance of the landslide after failure suggested that this was likely to be a translational failure with a rock mass sliding outwards on a surface inclined northwards out of the slope. The subsequent investigations have confirmed this interpretation. Although this mechanism is a well-known form of rock slope instability, large failures of this type are unusual in Hong Kong and, indeed, the Fei Tsui Road landslide is the largest recorded rapid onset failure in a permanent cut slope in the Territory.

3. REVIEW OF GEOTECHNICAL ENGINEERING OFFICE REPORT

The GEO report will now be reviewed on a section-by-section basis.

"1. Introduction

The introduction to the report provides the setting to the landslide event and outlines the main components of the investigations carried out. The method and scale of the investigation was wholly appropriate to the nature of the landslide.

2. Description of the Site

The site description, together with the figured maps and photographs, provides an adequate factual description of the site which is on Government land. Attention is drawn to the interpretative nature of the layout of the surface drainage system, and the observations made with regard to blockage of drains.

3. Description of the Landslide

The description of the landslide covers the geometrical form of the landslide, and the nature and distribution of the resulting debris. The unusual size of the Fei Tsui landslide is highlighted. Particular note should be taken of the runout distance of the debris which was longer than would be expected

for landslides in Hong Kong, indicating greater mobility of the slipped material at the time of failure. If the slide debris had behaved in accord with common rain-induced landslides in Hong Kong, then the main mass of debris would have probably extended to the middle of Fei Tsui Road.

Reference is made to the exposure of the 24-inch subsurface salt water main as a result of the landslide which was observed to be discharging water after the failure.

4. History of the Site

The site development history is outlined in this section. There is some uncertainty as to the reason for the presence of the strip of level ground below the slope but it is believed that consideration had been given at some stage to the eventual widening and extension of Fei Tsui Road to the southern side of Hong Kong Island. A consequence of this situation was that, although the slope was registered, and subject to various reviews and to the normal GEO procedures, it was physically detached from immediate proximity to Fei Tsui Road or to buildings.

Reference is made to the four small failures which occurred in the slope, two of which were formally reported to the Geotechnical Engineering Office (Geotechnical Control Office before 1991). In each case the debris was retained within the limits of the level ground in front of the slope. In the case of both the 1987 and 1993 incidents the base of the failure was about 10 m above ground level and involved the upper part of the slope. Inspection of the contemporary records and photographs indicates that the base of these failures was the same as that associated with the 13 August 1995 landslide. In the case of the 1993 failure fly rock broke some of the windows in the Baptist Church. As these windows were at a relatively high level, the landslide would have had to hit the ground with some force to generate fly rock on a steep enough trajectory. This could suggest that the failure process was by toppling.

5. Analysis of Rainfall Records

A rain gauge is located on the roof of Wo Hing House about 220 m north of the landslide and the records which are available from this gauge since August 1979 were used to carry out an evaluation of the intense rainfall to which the slope was subjected in relation to previous events.

The rainfall in Hong Kong in August 1995 was the highest ever recorded in the month of August based on records at the Royal Observatory, the rainfall being particularly heavy in the early part of the month. The rainfall recorded by the gauge was the highest recorded at that site for any rainstorm event for durations exceeding 7 days. The rainfall intensities for periods shorter than 12 hours are comparable to the highest intensities recorded in previous events.

6. Sequence of Failure

There were a number of witnesses to the landslide, including police officers, so that a reliable reconstruction of the timing of the two-stage sequence (described in Section 2. above) has proved possible.

7. Characterisation of the Subsurface Conditions at the Site

7.1 Geology

The geological conditions have been investigated by means of mapping of the landslide area after most of the debris had been removed, trenches and boreholes. The landslide took place in volcanic rocks grading from predominantly completely to highly decomposed tuff at the top of the slope to predominantly moderately to slightly decomposed tuff in the lower part of the slope. The rock mass is jointed with two through-going steep joint sets dipping west-north-west and north-east respectively; these sets together define the backscarp of the landslide.

The geological feature of greatest interest in the slope is the presence of an extensive layer of kaolinitic clay, up to 0.6 m in thickness and associated with clay veining, derived from alteration of tuff. This layer undulates, having a northerly dip varying in angle from 10 to 25°; some of the undulation may be the result of offsetting by small-scale faulting. The characteristics of this kaolinitic layer has been studied in particular detail by GEO.

The kaolinitic clay layer has been interpreted as a shear zone parallel to the original bedding of the tuff. The original material within the layer could well have been altered and deformed during the intrusion of the Kowloon granite Pluton which outcrops about 70 m north of the landslide. There is a set of joints which dip northwards at 10° to 25°, approximately parallel to the clay layer. The basal surface of the landslide on

which the displacement took place did not follow the kaolinitic layer precisely. In the upper part of landslide the surface is above the layer (within altered tuffs with kaolinite veins) but, in the lower part, layer and surface appear to be the same, although much of the clay was stripped off by the sliding debris.

7.2 Soil and Rock Properties

A comprehensive series of classification, strength and consolidation tests has been carried out on the materials within the landslide that are relevant to the stability of the slope including the kaolinitic clay layer and veins, altered tuff and weathered volcanic joints.

A range of shear strength values has been established dependent on the relative proportion of kaolinite, and associated veining, with the altered tuff. The lower bound value of $\phi' = 22°$, $c' = 0$ was assigned to the situation where shearing was through soil with a higher kaolinite content, and $\phi' = 29°$, $c' = 0$ was considered representative of the kaolinite-rich altered tuff layer which formed the basal failure surface of the landslide.

7.3 Groundwater Conditions

Two groundwater regimes are recognised at the site, a deeper regional water table, and a shallower perched water table retained by the kaolinitic clay layer at a higher level.

The regional water table, as based upon observations in boreholes drilled after the landslide, is 4 to 8 m below the kaolinitic clay layer. As noted earlier in this report (Section 2) the site is located on the side of a spur extending out from the higher ground to the south-west. In such a topographic situation the groundwater flow from the higher ground will tend to be diverted away the spur, and so any mound in the groundwater level beneath the spur will need to be sustained by local infiltration.

A perched water table was developed on top of the kaolinitic clay layer, and there is documentary evidence of minor seepage having been observed in the rock face at or above the level of this layer. Seepage, which increased with rainfall, was also observed above the kaolinitic clay layer within the landslide area during the investigations. As there was no evidence of significant seepage at the toe of the backscarp of the

landslide, about 5 m above the kaolinitic clay layer, it is concluded that the perched water level was probably in the range 1 to 4 m above the kaolinitic clay layer.

8. Conditions of Chai Wan Salt Water Service Reservoir and the Associated Water Main System

The Salt Water Reservoir is briefly described and, as based on the pumping record, it is recognised that there were no signs of abnormal operation nor major leakages before 0115 on 13 August 1995 which was the time of the second, main, failure. A leakage test was carried out in the west compartment (the east compartment is being kept empty for safety reasons) and no measurable leakage was detected.

A 21 m section of the 24-inch salt water main was severed during the landslide and water discharged for some time into the slope debris. All the dislodged pipe sections were retrieved and no signs of any old or sustained leakage through the pipes or joints were found.

These observations demonstrate that gross leakage from the Salt Water Reservoir was not a factor in triggering the landslide.

Nevertheless, a programme of chloride determinations was carried out on both soil and water samples in order to establish the extent of any salt water seepage. Elevated chloride contents were found in the regional groundwater in boreholes DH9 about 20 m north of the Reservoir and DH16 about 90 m north-east of the Reservoir indicating that seepage has almost certainly occurred from the Reservoir over a period of years. There are also significant chloride contents in seepages discharging from the cut slope west of the landslide, and in a seepage above the landslide basal surface. Soil samples from the extreme western part of the landslide have higher chloride contents which probably represent contamination by the salt water from the severed pipeline. In contrast the chloride contents of soil samples from the main part of the landslide and the eastern back scarp are lower and these soils were almost certainly not contaminated by the discharge from the fractured 24-inch water main. The presence of chloride in the seepages, above expected natural levels, and in the soil samples from the main part of the landslide basal surface, provides confirmatory evidence of the role of the kaolinitic clay layer in developing a perched water table condition.

9. Engineering Analyses

The engineering stability analyses carried out are based on the assumption that translational sliding took place on a surface inclined at 20° out of the rock slope with detachment from the backscarp on weathered volcanic joints. This is a reasonable geological model for the site conditions.

If no water pressure was assumed to be acting on the slide mass then failure would occur if the angle of shearing resistance (ϕ') was 25° or less. Such a value for ϕ' is within the range of measurement but less than the value (29°) considered to be a reasonable operational value.

The analysis has assumed that perched water conditions would give rise to effective water heads on the slide surface of 1, 2 and 4 m, which would theoretically give rise to failure if the values of ϕ' for the slide surface were 26.5°, 28.0° and 31.5° respectively. Hence it is concluded that, on the basis of reasonable assumptions regarding the perched water table conditions, instability could theoretically occur through translational failure.

The backscarp of the landslide is defined by two sets of steep joints and behind the crest of the failure there is some surface cracking on directions similar to these sets, although the extent of these cracks has yet to be explored laterally or in depth. In conditions of heavy rain such cracks may become rapidly filled with water and so an alternative groundwater assumption can be made that, for a ϕ' of 29° for the slide surface, the slide mass could be displaced by water pressure acting within steep, open joints within the whole of the backscarp. Under such circumstances the upper 9 to 10 m of the joint system would have to be filled with water for theoretical instability to be achieved. It is possible that this process could be a contributory factor to the slope failure process.

10. Diagnosis of the Landslide

This section provides a comprehensive overview of the slope failure process as derived from the results of the investigations carried out. The writer is in agreement with this analysis.

The Fei Tsui landslide was the result of the effect of elevated groundwater conditions, following an exceptionally wet

period of some days length and during an intense rainstorm, on a continuous, bedding-controlled layer infilled by relatively weak materials. Several of the features associated with the landslide are unusual although not exceptional: the extremity of the rainfall event and its antecedent history, the existence of a bedding-controlled planar layer in volcanic rocks, the presence of significant amounts of kaolinitic clay, and the size of this translational failure.

The first, small landslide could have resulted from toppling or a combination of sliding and toppling. This initial movement may have had a role in relation to a progressive unlocking of the process which then permitted the subsequent, larger failure to take place a short time after. Within that period of twenty minutes there may have been a series of progressive, albeit minor readjustments which contributed to the eventual failure mechanism and relatively long runout of the failed debris.

Although evidence has been identified of chloride contamination in the groundwater and soil which can almost certainly be ascribed to long-term seepage from the Salt Water Reservoir, there is no evidence that gross leakage contributed in any way to the triggering of the landslide.

11. Conclusions

The conclusions are a very brief re-statement of the cause of the landslide with which the writer is in agreement."

4. CONCLUSIONS ON GEOTECHNICAL ENGINEERING OFFICE REPORT

The investigation carried out by the Geotechnical Engineering Office into the Fei Tsui Road landslide has been comprehensive, having been executed in a professional manner. The Report accurately reports the conclusions of the investigation, and reaches a logical conclusion as to the contributory factors to, and cause of, the landslide. The writer is in agreement with the report on all essential matters.

5. LESSONS TO BE LEARNT

The Fei Tsui landslide has not identified any new feature not previously recognised in geological or landslide prevention practice within Hong Kong. However, there are features relevant to the cause of the landslide and the history of the site which deserve to be highlighted.

5.1 Structural Controls on Landsliding in Volcanic Rocks

The failure surface of the Fei Tsui Road landslide was bedding-controlled and no translational failures of this scale and type have been reported previously in Hong Kong. As the volcanic rocks of Hong Kong have been folded, any bedding that is present may result in unfavourable combinations of bedding dip and direction, and topography. There is the possibility that the type of condition which exists at Fei Tsui Road may occur elsewhere.

The review of the site history (Appendix A, A.2.2) has identified previous documentation on the site. A contemporary report on the slope written at the time of site formation refers to "a prominent horizontal weathered seam midway between the road and the berm (plate 8)" "approximately 100 mm wide and at least 50 m long". The "plate 8", taken in 1976, which is presented as Plate 2 to the GEO Report, illustrates the site of the Fei Tsui landslide. The very obvious planar geological structure observable in this 1976 photograph is presumably the "prominent horizontal weathered seam". However, it is obvious that this structure is not horizontal but rather it is a throughgoing feature dipping out of the face at an angle which might potentially lead to sliding. Even though the slope was looked at by other organisations subsequently, the possibility that this geological structure might induce a large translational failure does not appear to have been explored.

With this hindsight knowledge, it is necessary to recognise that continuous discontinuities dipping outwards at angles of 20° (and possibly less) from rock faces can result in translational failures.

5.2 Mineralogical Controls on Landsliding in Volcanic Rocks

The presence of kaolinite is not unusual in altered or weathered rocks in Hong Kong. In this case what is unusual is that the kaolinite was present as a relatively thick, continuous layer. Such layers might not be recovered by conventional diamond drilling, being washed away within the water flush, unless their presence was suspected and special measures taken to recover the material.

At this stage the factors which resulted in the development of the kaolinitic clay layer associated with altered tuffs at Fei Tsui Road cannot be stated with sufficient precision to enable such materials to be predicted.

5.3 Multiple Small-scale Failures

Four small-scale failures occurred at Fei Tsui Road over the period of two decades since the original site formation. In some other cases of slope instability in rock, such failures have proved to be the harbinger of an eventual larger failure.

Methods should be identified, within the GEO integrated approach towards landslide prevention, whereby multiple failures over a period of years at a single site can be identified for appropriate forensic study.

5.4 Leakage from Service Reservoirs

Although in this case gross leakage from the Salt Water Reservoir did not contribute to triggering the landslide, there was evidence of soil and ground water contamination through long term seepage. The possibility needs to be borne in mind that leakage from service reservoirs can influence local groundwater conditions, and this may in turn influence slope stability.

6. REFERENCES

GEO (1996). Report on the Fei Tsui Road Landslide of 13 August 1995. Volume 2: Findings of the Landslide Investigation. Geotechnical Engineering Office, Hong Kong, 68 p.