ASSESSMENT OF GEOLOGICAL FEATURES RELATED TO RECENT LANDSLIDES IN VOLCANIC ROCKS OF HONG KONG PHASE 2A - CHAI WAN STUDY AREA

GEO REPORT No. 60

S.D.G. Campbell & N.P. Koor

GEOTECHNICAL ENGINEERING OFFICE
CIVIL ENGINEERING DEPARTMENT
THE GOVERNMENT OF THE HONG KONG
SPECIAL ADMINISTRATIVE REGION

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PREFACE

In keeping with our policy of releasing information, we make available some of our internal reports in a series of publications termed the GEO Report series. The reports in this series, of which this is one, are selected from a wide range of reports produced by the staff of the Office and our consultants. A charge is made to cover the cost of printing.

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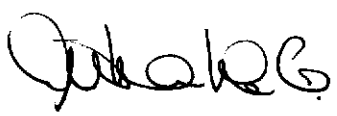

Andrew Malone
Principal Government Geotechnical Engineer
April 1998

FOREWORD

This report describes geological features in the Chai Wan area of eastern Hong Kong Island in relation to the stability of cut slopes. The assessment forms part of a programme of investigations carried out by the Planning Division of the Geotechnical Engineering Office following the fatal landslides at Fei Tsui Road and Shum Wan Road in August 1995.

Dr. S.D.G. Campbell undertook most of the field observations of geological features. Mr. N.P. Koor was responsible for the engineering geological assessment of the significance of these features, including those described in ground investigation reports. Mr. K.A. Emery, of the Department of Land and Water Conservation of New South Wales, carried out aerial photograph interpretation of the entire study area. The report makes recommendations for further investigations of selected cut slopes where adverse geological features are suspected. Recommendations are also made with respect to a related study of the Aberdeen study area (Phase 2B of the project).

The speedy and accurate digital compilation of the maps by staff of the Cartographic Unit of Planning Division, namely Mr. K.W. Wong (who directed the work), Mr. Samson Lee, Ms. Celina Ho and Ms. Julia Chu, made a significant contribution to the project. Technical support was provided mainly by Mr. K.C. Yip, Mr. Dicky Chan and Mr. George Cheng.

R.P. Martin
Chief Geotechnical Engineer/Planning

ABSTRACT

This report cover the phase 2A assessment of geological features related to recent landsliding in the Chai Wan area. Phase 2B covering the Aberdeen area will be reported separately. The study involved aerial photograph interpretation (API), a geological survey and an engineering geology assessment, including a desk study with limited field checking. A sensitivity analysis of the stability with respect to planar failure of slopes recommended for further investigations was also carried out. The reports includes eight 1:5 000-scale thematic maps.

This study concentrated on identifying slopes that are geologically similar to the one that failed at Fei Tsui road, and that have had similar histories of persistent seepage and multiple minor failure. The key geological features that influenced the Fei Tsui Road landslide were thick, laterally-extensive concentrations of kaolin dipping out of the slope face subparallel to the volcanic fabric and persistent steep joint sets.

The API examined a broader area than the main study area. Many relict landslide features were observed and classified according to the nature of the slope in which they occur. Very few recent landslides (post-1945) were noted on natural slopes. Some substantial landform features, evident as topographic depressions, were though to be associated with landsliding but their origin is uncertain. Photolineaments were also mapped and slopes showing evidence of persistent seepage highlighted.

The geological survey focused on identifying the orientation of eutaxitic foliation (the primary fabric in the volcanic rock). These fabrics provide the best way of identifying cut slopes that could contain adverse bedding-parallel features, as at the Fei Tsui Road landslide, but where such features are obscured by protective covering (chunam, shotcrete, etc.). The study showed that, although shallowly-inclined fabric (up to 20 or more) occur, major adverse bedding-parallel features are relatively unlikely, as stratigraphic breaks and persistent bedding planes are uncommon. More often, however, abrupt, planar, shallowly-inclined (5-20) discontinuities occur at the PW90/100 to PW0/30 rock mass weathering zone interface. These are typically loci for kaolin concentration that can be laterally continuous, especially along stress-relief joints (which also localise seepage), hence mimicking one of the main geological conditions at the Fei Tsui Road landslide site. The style of weathering of these largely fine ash tuffs differs from the corestone profiles often regarded as typical in Hong Kong. Closely- to widely-spaced subvertical joints, subparallel to the main faults, are virtually ubiquitous so that release surfaces similar to those at the Fei Tsui Road landslide could occur in most cut slopes in the area.

The engineering geology assessment was based mainly on a desk study of information from a wide variety of sources. Site formation photographs were particularly useful in assessing the presence of clay-rich seams, and low-angle discontinuities. Ground Investigation (GI) boreholes also indicate the presence of kaolin across most of the area but mostly in material of weathering grade III or better, in contrast to observations made during the geological survey which indicate that most significant occurrences of kaolin are in material of grade IV and V. This disparity is interpreted in terms of incomplete borehole records of soil material.

Data used in the engineering geology assessment formed the basis of three thematic maps at 1:5000 scale showing landslide incidents, GI information and areas for which geotechnical reports are available. These data were integrated with observations from the API and geological survey to produce a further thematic map depicting seepages.

The study concluded that mime slopes (out of 193 registerable cut slopes and retaining walls) require more detailed inspection, (e.g. chunam/shotcrete strips, vegetation clearance) and further engineering geological assessment. Seven are in volcanic rocks and two in fine- to medium-grained granite. The slopes were selected because of the presence of, or potential for, adversely-orientated geological features, including kaolin seams. A sensitivity analysis concluded that plane failure was likely if the conditions at the Fei Tsui Road landslide site exist in the nine slopes. Further recommendations are made for GI of two photolineaments identified by API, and of large-scale landform features suspected to be associated with landsliding, and for a study of the engineering properties of kaolinitic clay-bearing, completely to highly decomposed tuff based on block samples from up to two slopes recommended for further investigation.

CONTENTS

1. INTRODUCTION

1.1 Objective of the Study

This report describes the results of Phase 2A of the project 'Assessment of Geological Features Related to Recent Landslides in Volcanic Rocks of Hong Kong'. The aim of the project is to identify locations where geological features occur that are similar to those that influenced the Fei Tsui Road and Shum Wan Road landslides of August 1996. This report deals specifically with a study area around Chai Wan in eastern Hong Kong Island. The Chai Wan area, which includes the site of the Fei Tsui Road Landslide, was recommended for further study, including field work, in the Phase 1 report (Strange, 1996) of the project. That report concluded that existing archival data alone were insufficient to identify with confidence and on a systematic basis, those slopes where adverse geological features, similar to those at Fei Tsui Road and Shum Wan Road, might exist.

The objective of the Phase 2A study was to identify cut slopes (>c.10s of metres in length) in which engineering geological features occur that are similar to those at the Fei Tsui Road landslide site (GEO, 1996), and to carry out a preliminary engineering geological assessment of such features. The features include:

(a) Thick (100s of millimetres) and laterally extensive (10s of metres) concentrations of kaolin in impermeable and weak layers within rock masses.

(b) Completely to highly decomposed tuff (Grade IV/V) along relatively planar rock seams that sit on slightly to moderately decomposed tuff (Grade II/III), that dip directly, or obliquely outward from rock slope faces at angles of >c.20°.

(c) Stratified volcanic rocks dipping directly, or obliquely outward, at angles of >c.20° from rock slope faces. The orientation of the stratification is commonly indicated by a primary eutaxitic fabric, but may also be associated with lithological variation.

(d) Persistent, closely to medium-spaced, tight and rough, planar, steep (dip >60°) joint sets that could form release surfaces.

(e) Zones of continuous seepage.

(f) Clusters of previous slope failures.

As granitic rocks occur adjacent to the volcanic rocks in the study area, some cut slopes in granite were also inspected to determine whether any of the above engineering geological features were present.

1.2 The Study Area

The study area (Figure 1) extends across the southern side of Chai Wan in easternmost Hong Kong Island, and comprises an elongate strip 4 km long, extending from the southeastern slopes of Pak Ka Shan (Mount Parker) in the west to Cape Collinson in the east.

The area is up to 1.5 km wide from north to south, with Chai Wan in the north and Pottinger Peak in the south (Plate 1). The area reported on here mainly falls on 1:1 000 topographic sheets 11SE-18D, 11SE-19C, 11SE-19D and 11SE-20C, as recommended in the Phase 1 report, but also includes minor extensions into parts of sheets 11SE-19B, 11SE-20A and 11SE-20B. These extensions enabled a more comprehensive coverage to be made of the geology and topography of features such as the pre-reclamation coastline to the northwest of the Siu Sai Wan housing estate. Due to a shortage of time, much of Sheet 11SE-18D was only assessed by API. Parts of sheets 11SE-20D, 11SE-24A, 11SE-24B and 11SE-25A were also assessed by API alone.In addition, a major cut slope in granite on the Hing Wah Estate on the north side of the area was also assessed.

The area includes several major housing developments, including the Fung Wah, Hing Wah, Wan Tsui, Chai Wan, Yue Wan and Siu Sai Wan estates, on lower ground along its northern side. These estates extend onto reclaimed land in the east and northeast. Large-scale cut slopes occur behind most of the estates.The higher ground along the southern side of the area includes several large cemeteries, ossuaria and columbaria, with extensive terracing and retaining walls along the hillsides. There is a large number of cut slopes along Cape Collinson Road, which crosses the area from west to east.

Map Nos. 1 to 6, attached to the end of this report, contain the main results of this study. The data were digitised at 1:1 000 scale for final presentation at 1:5 000 scale on a raster-scanned topographic base (Sheet 11SE-D).

2. AERIAL PHOTOGRAPH INTERPRETATION (API)

2.1 Objective

The objective of the API study was to identify and map a series of land surface features which might be related to land instability problems. The features mapped included the following (Map No. 1):

(a) All relict landforms formed by slope instability.

(b) Landforms which may contribute to new slope instability problems because of their effects upon infiltration.

(c) Previous landslides - recent (post-1945) and relict. All landslides occurring on natural slopes were mapped from a number of sets of low altitude aerial photographs. The API complemented the information already available as part of the current Natural Terrain Landslide Study (Map No. 1).

(d) Seepages from natural terrain, or cut and fill slopes.

(e) Signs of slope instability such as surface creep.

(f) Photolineaments, other than those which can be related to land use factors.

The entire API study covered an area of approximately 230 ha. The results were transferred to eleven 1:1 000 map sheets: 11SE-18D, 11SE-19B, 11SE-19C, 11SE-19D, 11SE-20A, 11SE-20B, 11SE-20C, 11SE-20D, 11SE-24A, 11SE-24B, 11SE-25A.

The boundaries of the API were set to coincide with catchment, map sheet or development boundaries but extended to ensure that critical catchment areas draining towards Siu Sai Wan and Chai Wan were included.

2.2 Methodology

The legend codes for the features mapped during the API are listed in Table 1. A list of the aerial photographs used during the API is also presented in Appendix 1.

The 1949, 1963, 1967 and 1992 aerial photographs were the most useful for mapping natural terrain features. The larger landform features are best interpreted from the 1967 aerial photographs because their intermediate scale (1:12 500) enables the entire slope from crest to toe to be viewed in the one photograph pair. However, they can also be seen in all sets of photographs dating back to 1949.

The smaller relict landslide scars are observed from 1949 onwards, but are less easily recognised in more recent photography because of increasing vegetation cover on the natural terrain. None of the relict landslide features has shown any detectable movement in successive aerial photographs.

The 1949, 1963 and 1967 aerial photographs were the most useful for mapping points of seepage discharge on natural terrain, photolineaments and small relict landslide features. More dense or overhanging vegetation in later photographs obscured these features.

All other landslides of recent origin are prefixed by the letter 'A', followed by the date they were first observed (e.g. 1949) and then the letters 'a to d' to indicate the amount of vegetation cover on these features.

Only at one site has a natural slope landslide been identified and this occurs within an area previously mapped as a small, relict landslide (grid reference 11SE-D, 842850 813565). It was observed on 1967 aerial photographs. The site has now been modified for part of the Chai Wan Chinese Permanent Cemetery.

2.3 Observations

2.3.1 Landform Features Suspected to be Associated with Landsliding

These features refer to large relict landforms, identified on the basis of abrupt changes in shape and slope gradient within the terrain and, in some cases, deduced from the presence of debris flow deposits downslope.

Eighteen such landform features, suspected to be associated with landsliding, were mapped. They range in size from 50 m x 50 m to 320 m x 270 m, and occur on the steep

terrain between Chai Wan and Siu Sai Wan. The largest feature occurs on a slope that was part of the former coastline, now to the south of San Wah Street, and its development may have been associated with coastal erosion.

They often appear to have involved the displacement of complete blocks or layers of unweathered and, or, partially weathered rock, but no inference can be made as to the mechanisms involved in their formation, or of the age of the movements. Smaller relict landslide scars occur within some of these large features and these are mapped as separate features. There is no evidence of movement on these features after 1945, the date of the earliest aerial photographs inspected.

The relict landform features, their debris deposits and any deposits of colluvium below them, generally correspond to the unit "Debris Flow Deposits" shown on the 1:20 000 published Geological Map (Sheet 11 - Hong Kong and Kowloon, Solid and Superficial Geology (GCO,1986)).

2.3.2 Seepages

Inferred heavy seepage was observed at the following sites, and its persistence assessed over time:

(a) From cut slopes on the southern side of Lin Shing Road in 1992.

(b) From cut slopes on the southern side of Siu Sai Wan Estate from 1989, soon after the slopes were cut. Shadows over these sites in 1992 and 1994 prevented any interpretations for these two years.

(c) From cut slopes on the southern side of Kai Tsui Court in 1989, 1992 and 1995. Seepage occurred at approximately the same location when the first slopes were cut between 1949 and 1963.

(d) Areas of seepages on natural terrain to the south of Siu Sai Wan were first observed in 1949 and again in 1967. Patterns indicating the presence of vegetation species that prefer a wet environment were used to identify the presence of seepage. Shallow slumping of soil within the zone of seepage was also identified.

Areas of seepages on cut slopes were inferred, based on a number of characteristics in the aerial photographs. These include: free standing water at the base of slopes, narrow dark bands on generally light coloured slope surfaces, dark tones within drainage gutters or channels, and dark tones across usually lighter coloured road surfaces. The dark tones can be either water, or mosses and ferns that only grow where there is abundant water.

2.3.3 Photolineaments

A photolineament identified within the area of a relict landform feature suspected to be associated with landsliding south of Siu Sai Wan (Map No. 1). The photolineament is seen

only in the 1967 aerial photographs as a straight line that runs transversely across the slope. It does not appear to correspond to any land use feature and is not observed in any later photographs.

Another photolineament higher up the same slope was observed in the aerial photographs from 1949 to 1967, and with less certainty in the 1995 photographs.

2.4 Aerial Photograph Interpretation Conclusions

The following conclusions can be drawn from the API work:

(a) Large-scale landform features associated with natural slope degradation processes have been identified on several slopes. Some of these features are suspected to be associated with previous landsliding, they extend downslope into areas of slope debris, and one may be associated with coastal erosion.There is no evidence of movement on these features subsequent to the earliest available aerial photographs from 1945.

(b) Heavy seepages were identified on cut slopes at several sites, and these correspond well with recorded and observed seepages, including those seen during the geological survey.

(c) Photolineaments running transverse to the slope were identified within an ancient landform feature south of Siu Sai Wan Estate.

3. GEOLOGICAL SURVEY

3.1 Objective

The objective of the survey was to examine significant geological features, especially within, and near cut slopes. The following were recorded where observed:

(a) Stratification of principal types of volcanic rocks, and in particular the orientation of eutaxitic fabrics in such rocks. (Note: Eutaxite is a term used for pyroclastic rocks in which welding has occurred, i.e. viscous deformation of vitric fragments, resulting in marked planar fabrics (GEOGUIDE 3, GCO,1988))

(b) Joint orientations.

(c) Fault orientations.

(d) Concentrations of kaolin.

(e) The nature of the weathering profile and locations of deep weathering.

(f) Landslide features in and adjacent to cut slopes.

(g) Seepages associated with discrete geological structures.

Due to time constraints, comprehensive coverage of the study area was not possible. It was necessary to concentrate on those parts of the area close to cut slopes.

As the natural slopes are thickly vegetated, traverses were largely restricted to the main roads and tracks in the area (Figure 2). In addition, slopes covered by colluvium, as observed during the API, were omitted from the survey. A few stream sections were also examined. However, as the streams commonly coincide with photolineaments and or follow faults, the information they provide is not necessarily representative of adjoining areas.

Generally, the cut slopes in the area are covered by chunam or shotcrete, and occasionally stone pitching. Commonly, in mixed soil and rock slopes in weathered rock, the upper parts of the slope are covered, whereas lower slopes in rock remain exposed, causing bias of observations towards the latter. However, small exposures commonly protrude through the chunam or shotcrete enabling some detailed observations to be made.

Areas of significant seepage were recorded during the survey. In most instances, seepage was associated either with shallowly-inclined joints or with the interface between PW0/30 and PW90/100 rock. Seepage was also noted in conjunction with steeply-inclined micaceous shears within the granite on the north side of Wan Tsui Road. The most significant examples of seepage, most of which were noted in cut slopes, are listed in Appendix 2.

The main results of the survey are shown on Map No. 2.

3.2 Volcanic Rocks

3.2.1 Correlation and General Structure

On the existing Hong Kong Geological Survey 1:20 000 scale geological map of the area, (Sheet 11, GCO, 1986; Figure 3) most of the study area is shown to be underlain by volcanic rocks of the Shing Mun Formation, with further volcanic rocks of the Ap Lei Chau Formation lying to the southwest. Since publication of Sheet 11 (GCO, 1986) most of the rocks shown as Shing Mun Formation have been reassigned, on the basis of their whole-rock geochemistry, petrography and isotopically-determined ages, to either the Mount Davis Formation, or to the newly defined Che Kwu Shan Formation (Sewell *et al.*, in prep.). Both of these formations have been proved to overlie the Ap Lei Chau Formation and their regional dip within the study area is mainly to the northeast, with variations largely towards the northwest and east.

On the basis of the regional stratigraphy alone, the orientation of stratification in the area can be inferred to dip, as at the Fei Tsui Landslide site, out of some of the cut slopes, most of which face to the northwest, north, or northeast. Field work has supported this interpretation of the regional structure. However, discrete, planar bedding features, reflecting abrupt changes in lithology, are rarely observed within the limited exposure available, although they have been inferred in some instances. Hence, even where the general structure dips directly out of a cut slope, this does not necessarily imply that a bedding-parallel feature, similar to that at the Fei Tsui Road Landslide site, exists within that slope.

The volcanic rocks are underlain by, or faulted against fine to medium-grained granite in the area north of Fei Tsui Road and in the northwest of the study area. Granite contacts shown on Map No. 2 are largely as depicted on the published geological map of the area (GCO, 1986) with minor modifications based on data from the Fei Tsui Road landslide investigations (GEO, 1996) and the present study. A granite contact was observed at only one locality during the field survey. The locality is in a stream section 120 m northwest of Hiu Fung House on the Fung Wah Estate, where the planar, contact, dipping at 85°/123°, is interpreted as a fault. The tuff in the hanging wall (downstream) is slightly hornfelsed, and contains thin quartz veins striking parallel to the fault, as does the adjacent granite. Neither the tuff, nor the fault are kaolinised, but a weathered seam along a shallowly-inclined sheeting joint (dip 38°/113°) in the granite immediately upstream of the fault contains some clay in addition to sand-sized material.

3.2.2 Lithology

The dominant rock types of the area are variably lithic and vitric lapilli- and coarse ash crystal-bearing fine ash vitric tuffs. Locally, crystals are sufficiently abundant to form lapilli- and vitric fine ash-bearing coarse ash crystal tuffs. Most of the rock types are bluish grey when fresh, but weather to a light bluish grey and eventually to a light brown, yellowish brown or reddish brown with increasing material decomposition. The crystals are mainly of feldspar and range from coarse ash (0.06-2 mm) to lapilli (2-60 mm) size. Quartz, biotite and iron-oxide crystals occur but are far less common. Eutaxitic (primary compactional) fabrics occur in some but not all of these rocks (Plate 2). Coarser lithologies also occur including lithic block-bearing lapilli-ash to coarse ash lithic and crystal tuffs. In the east of the area, south of the Siu Sai Wan Estate, lapilli tuffs and lapilli-ash tuffs predominate that include subangular, fine-grained rhyolitic lapilli up to 40 mm in size. Some of the coarser lithologies on high ground in the southern part of the area, especially to the northwest of Pottinger Peak, are eutaxitic and very calcareous. In these, the carbonate preferentially weathers to form ellipsoidal cavities.

Rapid changes in lithology, other than across faults, are uncommon, and no sedimentary horizons or major bedding planes were observed during the field survey.

3.2.3 Volcanic Fabrics

Most of the rocks are formed from deposits derived from explosive volcanic eruptions (as shown by broken crystals, subangular lithic clasts etc.). In many instances, they contain fabrics formed during compaction of the deposits soon after they were deposited and often while the deposit was still hot. These fabrics are often consistent over large areas and generally conform to the shallowly-inclined northerly, northeasterly and easterly regional dips of rock units in the area (Figure 3; Map No. 2). In the vicinity of faults, more variability may be seen.

Identifying primary volcanic fabrics is of particular importance to this study as they provide a means to establish the general dip of rock stratification despite the limited exposure available in most cut slopes with surface protection, and the infrequency of bedding planes.

Hence, in assessing geological features in cut slopes, it is possible to identify, or predict, those slopes in which stratification dips directly out of the slope, as at the Fei Tsui Road landslide site. Slopes in which the volcanic fabric, and hence any bedding planes, dip into the slope, would lack one of the basic geological features that influenced the Fei Tsui Road landslide.

The best examples of volcanic fabrics in the area are in coarse eutaxites on the northwest flanks of Pottinger Peak, in the Chinese Permanent Cemetery. The eutaxitic fabrics are evident because of aligned, flattened, fine-grained lapilli, up to 100 mm in size, that have been altered to quartz, chlorite, kaolin and calcite. The lapilli are subparallel to a more pervasive, wispy, finer fabric caused by aligned fine-grained lapilli and coarse ash lithic, crystal and coarse and fine ash vitric components.

Volcanic fabrics have been measured accurately at some localities, especially where coarse, flattened lapilli (fiamme) are present. More commonly, they were estimated only within broad limits, often because the rock type is too fine grained for the fabrics to be determined confidently. Locally, preferred alignment of tabular feldspar crystals provided valuable confirmation of the orientation. The volcanic fabrics are most readily observed in moderately decomposed rock.

The volcanic (eutaxitic) fabrics (Figure 4; Map No. 2) are generally shallowly inclined (<20°) to subhorizontal, and open folding plunging to the northeast and east can locally be inferred. Dips greater than 30° are localised and are often located close to the trend of regional faults.

Form lines, which display the general strike of the volcanic fabric, have been constructed (Map No. 2) across the area. The dip direction is generally shown in addition to the strike and representative estimates of the amount of dip have also been made. The density and continuity of the form lines are largely governed by the density and consistency of observed fabrics. It has not proved possible to construct form lines for all parts of the area, and the westernmost part of the area is particularly lacking in form lines due to the lack of observed fabric data. Unlike the lithological boundaries shown on Map No. 2, which vary in orientation with the topography, the volcanic fabric form lines are constructed irrespective of local topography.

The form lines have been used to predict the orientation of stratification in slopes that are completely covered by chunam, shotcrete, or stone pitching. Where the form lines and dip direction data suggest that stratification is inclined directly out of the slope, then an important geological bedding feature such as that which influenced the development of the Fei Tsui Road landslide could potentially exist in the slope. However, where the form lines indicate fabric, and therefore any stratification dipping into the slope, then close similarity to the geological features at the Fei Tsui Road landslide would be unlikely.

Slopes in which the volcanic fabric was observed to dip directly out of the slope, or at a high angle to its strike, are listed in Appendix 3A. Slopes in which the volcanic fabric is inferred from fabric form lines to dip directly out of the slope, or at a high angle to its strike, are listed in Appendix 3B.

3.2.4 Joints

Systematic rock joint surveys were not possible for all of the cut slopes in the area within the time available, but major joint sets were measured on a regular basis. The joint data, shown in Figure 5, highlight the consistent orientations of the main joint sets. No significant differences in joint orientations were observed across the area.

The east-northeast and north-northwest striking joint sets are both steeply inclined (>70°). These orientations are generally subparallel to the main faults and photolineaments. Similar orientations of steeply-inclined joints were observed at the Fei Tsui Road landslide site (GEO, 1996). Some of the steeply-inclined 'joints' have been the loci of minor faults, as shown by slickensides. The shallowly-inclined joints are more variable, and often have a significant down-slope component of dip in relation to the topography. Hence, they are interpreted mainly as stress relief joints caused by weathering and erosion.

3.2.5 Faults

The main faults shown on the published geological map (Sheet 11, Figure 2) have been confirmed by field observation (Map No. 2). The two main fault sets strike northeast varying to east-northeast, and northwest varying to north-northwest. Minor faults of both orientations were commonly observed. Faults trending slightly west of north also occur. The faults form topographic depressions, reflecting relatively deep weathering, as on the northeast side of Lin Shing Road. The depressions also tend to be partly infilled by superficial deposits.

The pre-reclamation coastline comprised linear sections parallel to the two main fault trends and is inferred to have been influenced in its development by faults.

3.2.6 The Presence of Concentrations of Kaolin

Concentrations of kaolin were noted where seen and occurrences are shown on Map No. 2. Such concentrations were rarely seen in fresh to moderately decomposed rock, except for discrete discontinuity infillings close to the PW0/30 and PW90/100 rock mass weathering interface. Kaolin concentrations, generally 10 mm or less thick but locally up to tens of millimetres thick, are more common in the more intensely weathered rock profile. They infill steeply- and shallowly-inclined discontinuities, and occur as white and buff clays. Laterally continuous kaolinitic clay infillings are rarely exposed but can occur at the PW0/30 and PW90/100 rock mass weathering interface. Although exposure of this interface is limited due especially to the vegetation cover at this level in the weathering profile, kaolin concentrations can be traced for tens of metres and possibly more. Similar, laterally continuous concentrations occur within the PW0/30 rock mass. The most continuous observed example is on the southwest and northwest cut slopes (11SE-D/C187 & 188) beside the Siu Sai Wan Estate. Significant developments also occur in a granite slope (11SE-D/C49) on the northwest side of Wan Tsui Road.

The key observations are summarized below:

Siu Sai Wan

Kaolin concentrations at Siu Sai Wan appear near a relatively planar rock mass weathering zone interface between the PW0/30 zone and the PW90/100 zone (Plates 3-5). Such concentrations are often preferentially at or immediately above the interface (Plates 6-9). Kaolinitic clay is common along joints in the PW0/30 zone above the interface, and particularly those subparallel to the interface (Plates 10 & 11). However, kaolin concentrations were not observed more than two metres below the interface in any of the extensive cut slopes in rock (PW90/100) alongside the estate. Although the transition from PW0/30 to PW90/100 zone is abrupt (with the PW50/90 zone very thin or absent) and planar on a local scale, across the estate as a whole marked variations are seen in the depth at which the transition occurs. The most pronounced example of this variation (Plate 12) coincides with a northeast-southwest-trending fault that can be traced as a photolineament towards the southwest: the weathering transition steps upwards to the southeast across the steeply northwest-dipping fault. This fault-related feature is seen even more clearly in photographs taken during development of the slope (Plate 13). Other examples of fault-related control of the depth of weathering were identified during the development of slope 11SE-D/C181 (f. 69 in GCI 3/2/105) on the southeast side of the estate. Where the weathering transition is locally upwardly convex, significant seepage occurs, but seepage is more generally associated with the transition. Vegetation in general is concentrated at, and above the transition.

As the kaolinitic clay is largely restricted to the PW0/30 zone, it is probable that its formation is associated with weathering. Although the kaolinitic clay concentration at the interface tends to be inclined in the same direction as the topography of the natural slopes above the cut slope at Siu Sai Wan, in detail there is increasing variance with depth associated with the inclined geometry of the major faults (trending both northeasterly and northwesterly). The possibility that concentrations of kaolinitic clay were formed as a result of hydrothermal alteration at stress release joints cannot be ruled out.

The interface with kaolinitic clay concentration dips out of the slope on the northwest side of the estate (slope 11SE-D/C187 and in the northern part of 11SE-D/C188), and similar orientations also occur locally along the southwest cut slope (11SE-D/C188), and may also occur at some distance upslope from 11SE-D/C188.

Plate 8A in GEOGUIDE 3 (of an excavation at Siu Sai Wan; P.Strange pers. comm.) shows a similar geometry to that described above, with an abrupt interface between the PW0/30 and PW90/100 zones being accompanied by the presence of white, possibly kaolinitic clay veinlets within the PW0/30 zone and subparallel to the interface.

Slope 11SE-D/C49, Northwest Side of Wan Tsui Road

The engineering geology desk study highlighted this slope for investigation as a report (see Section 4.2.4) suggests the presence of 'talc'. Rather than talc, white kaolinitic clay was observed in this slope. The clay occurs along several, shallowly-inclined, subparallel, intensely weathered seams (Plates 14 & 15) within the cut slope in fine- to medium-grained granite on the northern side of Wan Tsui Road, below the Hing Wah Estate. The intensely weathered seams are typically tens of millimetres, and locally up to 300 mm thick, and are infilled with sand-sized material and lenses of white kaolinitic clay. The seams appear to persist laterally for several metres but the exposure is not readily accessible. Between the weathered seams, granite of the PW90/100 zone (comprising predominantly Grades II and III

rock) is present, occurring as joint-bounded slabs up to several hundred millimetres thick (Plate 15). The weathered seams dip at 24-40°/055-098° with 24-27°/070-090° being typical. The strike of the cut slope is 017° so that the discontinuities have a significant dip component out of the slope. The maximum outward dip component is at the northeast end of the slope, and plunges towards the T-junction between Wan Tsui Road and Chai Wan Road.

Slope 11SE-D/C98, West side of Cape Collinson Road

A wide (c.100-150 mm), weathered, shallowly-inclined joint, infilled with completely decomposed tuff and kaolinitic clay can be seen at this slope (Plate 16). The joint locally steps and bifurcates across subvertical joints. The seam was traced for c.25 m.

Slope 11SE-D/C188, west of Siu Sai Wan

Prominent weathering of tuff occurs (Plate 17, 843435 813785) along a moderately wide (c.150 mm) joint at the northern end of the slope. The joint infill includes some kaolinitic clay. However, the joint is shallowly-inclined and generally dips into the slope,

3.3 Geological Survey Conclusions

The geological survey has identified the following important geological features:

(a) The bedrock geology mainly comprises a thick sequence of volcanic rocks, dominated by lapilli-bearing coarse and fine ash crystal and vitric tuffs, that are commonly eutaxitic.

(b) Lithological contacts are rarely exposed, and there are few major stratigraphical breaks in the sequence.

(c) Eutaxitic volcanic fabrics occur across most of the area. They dip mainly north, northeast or east at shallow angles (typically 0-25°). Their presence has enabled cut slopes in which outward-dipping stratification occurs, or might occur to be identified.

(d) Kaolin is far more commonly found in the PW0/30 rock mass weathering zone (of predominantly Grades IV and V material) than in the PW90/100 zone (of predominantly Grade III to I material). Kaolin often concentrates at, or parallel to the often abrupt and planar PW0/30 and PW90/100 interface. This suggests that the kaolin formed, or accumulated within discontinuities, during weathering.

(e) The PW0/30 and PW90/100 zone interface locally steps abruptly to different levels across faults trending both northeast and northwest. Deeper weathering was observed in the hanging wall of these faults.

(f) Faults mainly strike northeast, varying to east-northeast, and northwest, varying to north-northwest. They are associated with zones in which the orientations of volcanic fabrics may be anomalous.

(g) Two steeply-inclined joint sets are dominant and are subparallel to the main faults. The steep joints are locally infilled with kaolin, especially within the PW0/30 zone.

4. ENGINEERING GEOLOGY ASSESSMENT

4.1 Objective

An engineering geological assessment has been made of the study area, essentially through a desk study with limited field observations. Sources of information for the desk study were identified in the Phase 1 Report by Strange (1996). This section of the report summarises the information obtained from the desk study and assesses the engineering significance of the findings.

4.2 Summary of Information

4.2.1 Information Sources

The sources found most useful were the Landslip Incident Reports, Ground Investigation Reports, Stage 1 and Stage 2 Reports, GAS 8 Report and the Binnie and Partners Landslip Investigation Phase IIC Report. Tabulated lists of all the sources of information used in the desk study are contained in Appendix 4.

Relevant information extracted from the desk study is presented on four 1:5 000 thematic maps: each map is briefly described below. The maps were used initially to identify slopes that may potentially contain some of the features listed in Section 1.1. Site inspection was made at sites identified as having potentially similar engineering geological conditions to the Fei Tsui Road landslide.

4.2.2 Landslide Incident Map

The Landslide Incident Map (Map No. 3) contains the locations of all landslide incidents in the study area reported to GEO since 1982, together with landslide scars noted by Binnie and Partners (1977). A total number of 42 landslide incidents have been recorded in the study area since 1981. All but three of the incident reports were available for inspection.

The landslides have been split into five main groups, based on information contained on the Landslide Incident Reports such as volume of landslide and description of the failed material. The landslide groups are as follows: landslides greater than 50 m^3 in volume; landslides greater than 5 m^3 but less than 50 m^3 in volume; retaining wall failures; landslides less than 5 m^3 in volume; and surface erosion. The information recorded on the incident reports is generally not detailed enough to determine the nature of the failure material or the detailed mode of failure. However, photographs accompanying the report were more useful in determining the nature of the landslide and any relevant geological features.

Particular clusters of landslides were identified which, based on photographic evidence and geometry of landslide scar, indicate failure on shallowly dipping discontinuities. These are discussed briefly as follows:

(a) Three landslides are located on slope 11SE-D/C49, located below the Hing Wah Estate. Incident number HK 93/9/12 occurred on a shallowly inclined, planar discontinuity. Incident number HK 89/5/18 was a large failure (550 m^3) in partially weathered rock also occurring on a shallowly inclined, planar discontinuity. Heavy water seepage from above the failure plane was noted at the time of the inspection.

(b) Three landslides have occurred on the cut slope 11SE-D/C17 adjacent to San Ha Street. Landslide incident HK92/5/12 was a joint-controlled, small landslide of about 10 m^3 in volume. White clay can be seen on the photographs of the landslide close to the failure plane.

(c) Two shallow failures (HK 92/5/11 and HK 92/1/1) of about 25 m^3each have occurred on slope 11SE-D/C41 further east of the Fei Tsui Road failure of 1995. Both failures are within partially weathered rock.

Natural landslide scars mapped as part of the Natural Terrain Landslide Study being carried out by the Planning Division of GEO are presented on the Aerial Photograph Interpretation Map (Map No. 1). Only six such features have been identified within the study area.

4.2.3 Ground Investigation Map

The Ground Investigation Map (Map No. 4) summarises information contained in all the known ground investigations (GI) made in the study area. The boundary of each GI site is shown together with a summary of, the level of the top of continuous grade III rock (the level at which grade III or better rock occurs continuously in the drillhole), standing ground water level and the presence of kaolin if noted in the logs. The boundary between tuff and granite is indicated on the map where it can be determined from the GI data.

In total, 43 GI reports have been identified within the study area and these are listed in Appendix 4. Four reports were not available during the study period. The limitations of GI logs were recognised by Strange (1996). In general, the reports contained enough information to determine the approximate level of continuous grade III rock. Ground water records taken from standpipes or Cassagrande type piezometers installed in the drillholes are contained in most of the reports, but these water levels should be used with caution since the monitoring periods are generally for only one week following the completion of the GI. Kaolin is described either as smears or infillings of joints within grade III rock or better. In some cases, talc has been described and this is noted on Map No. 4.

Typically, the depth to top of grade III rock is 5 m to 10 m below original ground level. Contouring of the top of continuous grade III rock would be useful, but this could only be done where borehole data of sufficient density is available. Contouring should be done, where

possible, in any future phases of work. Areas of deep weathering all lie along the major faults shown on Map No. 2.

Kaolin as identified in the GI information appears to occur over the entire study area. Kaolin has been identified within rock of grade III or better material as smears or infillings along joints. This is in contrast to site observations where kaolin concentrations have been identified within PW0/30 rock masses of predominantly grade IV/V rock rock at the interface with the PW90/100 rock mass zone and only rarely observed within the P/W90/100 rock masses. This variance is probably sampling related since the kaolin development horizon at the PW0/30 and PW90/100 rock mass weathering zone interface would be difficult to sample. Also, kaolin concentrations recovered from the PW0/30 zone would mostly be contained in Mazier tubes and not necessarily described. Locations where significant amounts of kaolin have been recorded in the GI reports are summarised below:

(a) Significant kaolin bearing joint infills up to 5 mm thick were recorded in drillhole C5 in the natural slope above the Chai Wan Estate (Map No. 4). Several other drillholes made in this slope also recorded kaolin bearing joint infills on 45° to 70° dipping joints.

(b) The GI made on the cut slope 11SE-D/C18 (Map No. 6) behind Chai Wan Estate notes slickensided kaolinitic clay bearing infilled joints up to 25 mm thick.

(c) Talc infills up to 20 mm thick on low angle joints were reoprted in the GI report for the slopes 11SE-D/C34 and D/C49 located below the Hing Wah Estate. This is likely to be kaolinitic clay rather than talc.

4.2.4 Report Map

The Report Summary Map (Map No. 5) shows the distribution of the various reports studied, annotated with salient information which is summarised below:

(a) Slopes 11SE-D/C34 and C49 located below Hing Wah Estate. Zones of extensive seepage (Map No. 6) along both slopes from above low-angle sheeting joints which tend to dip in an easterly direction and daylight in slope 11SE-D/C49 are reported. Photographs in the reports show continuous undulating sheeting joints daylighting in both cut slope faces.

(b) Slope 11SE-D/C14. (Plates 17 & 18) Reports note that the interface between the PW0/30 and PW90/100 zone dips in a northerly direction.

(c) Slope 11SE-D/C17 adjacent to San Ha Street. Low-angle joints dipping out of the rock cut slope are evident in photographs, together with what appears to be some low-angle zones of partially weathered rock. Extensive seepage is noted in the slopes behind Chai Wan Estate (Map No. 6).

(d) Joint data contained in Table 4C in the body of the GAS 8 Report is presented in Figure 6 as a contoured stereoplot of pole concentrations. Four major pole

concentrations can be identified; two sub-vertical joint sets trending east-northeast and north-west which are in the same approximate orientation to the trend of major faulting and photolineations in the area, a low-angle set of sheeting joints with variable dip direction, and a high angle set with dip and dip direction 70°/165°.

(e) Slopes behind Wan Tsui Estate. A weathered seam of unknown decomposition grade in one slope appears to be about 200mm thick within grade II tuff. The seam dips at a low angle, is irregular in form, and appears to step to different levels across vertical joint sets.

(f) Slopes behind Siu Sai Wan Estate. A prominent weathering front is clearly visible (Plate 13).

(g) Slopes 11SE-D/C182 & D/C183 behind Siu Sai Wan Estate. The principle cause of the failure at these slopes was considered to be a combination of high pore water pressures, low mass strength of the soils and a relatively thick zone of intensely weathered rock. Kaolin development along relict joints in the weathered PW0/30 rock mass was noted.

(h) Slope 11SE-D/C181. Photographic records of the slope during site formation showing, in particular, zones of deep weathering having almost vertical interfaces with grade II rock. The interfaces are fault-controlled, the deeper weathering front being on the hanging wall side of the fault.

(i) Fei Tsui Road Landslide. A detailed report on the cause of landslide is available (GEO, 1996).

4.2.5 Seepage Map

The Seepage Map (Map No. 6) presents data on historical and present-day distribution of seepage within the study area. Seepage information has been obtained from Binnie and Partners 1977-78 Slope Catalogue, Stage 1 and 2 Study reports, GAS 8 Report, API interpretation and data collected during the field survey for this study.

Slopes which have had major historical and present-day seepage include: slopes 11SE-D/C49 and D/C34 below Hing Wah Estate; slopes 11SE-D/C17, D/C18 & D/C19 behind Chai Wan Estate; slopes 11SE-D/C181, D/C188 & D/C189 behind Siu Sai Wan and Siu Sai Wan Estates; and the slopes north of Fung Wah Estate.

4.3 Discussion

4.3.1 General

Based on the API, geological mapping and the engineering geology desk study, slopes which are suspected to have similar features to the Fei Tsui Road landslide site have been identified. These slopes are identified below together with a brief justification for listing each of the features. It should be emphasised that the slopes below have been identified only as

being potentially similar to the Fei Tsui Road slope. Further work in the form of ground investigation will be required to check whether or not they are actually similar. The findings are summarised in Table 2.

4.3.2 Slope 11SE-D/C41 Adjacent to Fei Tsui Road

Both the eutaxitic fabric and the interface separating the PW0/30 and PW90/100 zones dip out of the slope face, groundwater seepage is observed, the slope is adjacent to the Fei Tsui Road landslide and strikes in the same direction.Two landslides have been observed in this slope.

4.3.3 Slope 11SE-D/C17 Adjacent to San Ha Street

Unfavourable conditions including previous joint-controlled failure with evidence of kaolin on the failure surface, groundwater seepages, eutaxitic fabric dipping out of slope face, and low-angle joints and weathered zones are identified in this slope.

4.3.4 Slopes 11SE-D/C18 and D/C19 Behind Chai Wan Estate

These two slopes showed historically heavy seepages and kaolinitic clay recorded during GI within and above the slopes.

4.3.5 Slopes 11SE-D/C187 & D/C188 Behind Siu Sai Wan Estate

These slopes showed kaolinitic clay development along the planar PW0/30 and PW90/100 interface with heavy historical seepage, some adverse orientations of the PW0/30 and PW90/100 interface mapped, and eutaxitic fabric commonly dipping out of the face of slope 11SE-D/C188.

4.3.6 Slope 11SE-D/C23 Along Chai Wan Road Below Chai Wan Swimming Pool

This slope showed heavy seepages and a potentially adverse interface between PW0/30 and PW90/100 zones with kaolinitic clay development.

4.3.7 Slopes 11SE-D/C34 and D/C49 Below Hing Wah Estate

These are cut slopes in granite with historically heavy seepage, a landslide incident cluster (two of which occurred on low-angle discontinuities), weathered seams with kaolin development (dipping obliquely out of the slope), kaolin observed in drillhole records and evidence of incipient movement above weathered seams.

4.3.8 Slopes Checked by GCO/GEO

Out of the nine slopes, it appears from records obtained from the Island District Division that five have been checked by GCO/GEO (Table 2). LPM works were carried out on the two granite slopes below the Hing Wah Estate in 1992-93. The slope designs have been examined to determine whether the engineering geology has been adequately investigated. The designs have been reviewed in the light of study information.

All of the slope stability analyses contained in the checking files have considered, in some form, failure along low angle, low strength discontinuities. However, the strength parameters adopted are higher than the lower bound values obtained in the Fei Tsui Road landslide investigation. As such, plane failure was not considered a major potential failure mechanism and therefore slope designs did not take this into account.

Therefore, none of the above nine slopes can be discounted based on the analyses submitted for checking.

4.3.9 Sensitivity Analysis

A sensitivity analysis has been carried out using an idealised model to determine whether plane failure is likely to occure in the above nine slopes if the Fei Tsui Road conditions exist. The following simplified assumptions have been made: (i) plane failure is possible along a kaolinitic clay infilled seam dipping out of the slope, (ii) the kaolinitic clay infilled seam occurs at the interface between PW0/30 and PW90/100 rock mass weathering zones, (iii) shear strength parameters of friction angle (ϕ) = 22° and cohesion (c) = 0 kN/m^2 are adopted from the lower bound shear strength parameters for the sliding surface obtained from the Fei Tsui Road landslide investigation and, (v) the graphical stability analysis method is used for plane failure after Hoek and Bray (1981).

The results of the sensitivity analysis demonstrate that if the Fei Tsui Road type conditions exist in the nine slopes identified above there is potential for plane failure, especially if the sliding surface dips at 20° or greater out of the slope face. Such unfavourable conditions have been identified by measurements on slopes 11SE-D/C187 and 11SE-D/C49. They also occur locally at slope 11SE-D/C188, but have only been inferred from information from the desk study and the geological survey at the other six sites. Details of the analysis and justification for the above assumptions are contained in Appendix 5.

From the sensitivity analysis, it is concluded that further investigation will be required at all nine slopes.

5. CONCLUSIONS

As a result of the desk study and limited field mapping, and integrating the results of the API and geological survey, of the 193 registerable cut slopes or retaining walls identified in the SIFT Study within the study area, nine slopes may have engineering geological conditions similar to those at the Fei Tsui Road landslide site. It has been demonstrated that if

conditions similar to those at the Fei Tsui Road landslide do exist, then plannar failure of these nine slopes is possible. The location of each of these slopes are shown on Map 6 and are as follows:

(a) Slopes 11SE-D/C49 and D/C34 below Hing Wah Estate.

(b) Slope 11SE-D/C41 adjacent to Fei Tsui Road.

(c) Slope 11SE-D/C17 adjacent to San Ha Street.

(d) Slopes 11SE-D/C18 & D/C19 behind Chai Wan Estate.

(e) Slopes 11SE-D/C187 & D/C188 behind Siu Sai Wan Estate.

(f) Slope 11SE-D/C23 along Chai Wan Road below Chai Wan Swimming Pool.

6. RECOMMENDATIONS

On the basis of this study it is recommended that:

(a) The slopes listed in Section 5 above (with the exception of slopes 11SE-D/C49 and 11SE-D/C34, both of which had already been injected out of turn into the LPM programme as this report was being compiled) should be investigated further. The ground investigations (GI's) should consist of chunam strips, trial pits, drillholes and some laboratort testing. Block samples for testing should be taken from cut slope 11SE- D/C188 and/or 11SE-D/C187.

(b) The two transverse photolineaments identified crossing the natural slope south of the Siu Sai Wan Estate are investigated by means of an initial inspection after vegetation clearance followed by trial trenches if necessary.

(c) Trial trenches are excavated to investigate the nature and allow interpretation of the large-scale landform features, identified by API and suspected to be associated with landsliding.

(d) In conjunction with the GI, an initial literature review of the engineering properties of kaolinitic clay-bearing, completely to highly decomposed tuff is required in conjunction with some laboratory testing.

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LIST OF TABLES

Table 1 - Mapping Legend for the API

MAP FEATURE	TERRAIN TYPE	DEFINITION AND/OR SYMBOLOGY	CODE
Landslide scar	natural slope	relict feature with obvious head scarp	A
	natural slope	relict feature with no obvious head scarp	B
	cut slope	landslide scar within, or touching, a cut slope	C
	fill slope	landslide scar within, or touching, a fill slope	D
	natural slope	fresh landslide scar, bare of vegetation	F
	cut slope	fresh landslide scar, bare of vegetation	G
	fill slope	fresh landslide scar, bare of vegetation	H
Landforms features, suspected to be associated with landsliding, including landslide debris		relict feature suspected to have been formed by a large scale failure within the rock mass and/or weathered or colluvial material.	E
Photolineament			J
Seepage			S
Surface creep		terracetting within surface materials	T

Table 2 - Engineering Geology Assessment Summary

Slope No. 11SE-	D/C41	D/C17	D/C18	D/C19	D/C187	D/C188	D/C23	D/C34	D/C49
Kaolin clay rich seams	×	√	√	√	√	√	×	×	√
Seams latlerally extensive (>5m)	×	×	×	×	√	√	×	×	√
Seams relatively planar	×	×	×	×	√	√	×	×	√
Seams dip > 20° out of slope face	×	×	×	×	√	×	×	×	√
Eutaxitic fabric dips out of slope surface	√	√	× / √	× / √	× / √	× / √	√	×	×
Eutaxitic tuff	√	√	√	√	√	√	√	×	×
PW0/30 on top of PW90/100 rock	√	×	×	×	√	√	√	×	×
Steep joint sets as release surfaces	√	√	√	√	√	√	√	√	√
Past failure clusters	√	√	√	√	×	×	×	×	√
Seepage	√	√	√	√	×	√	√	√	√
Slope checked by GCO / GEO	×	×	√	×	√	√	×	√	√

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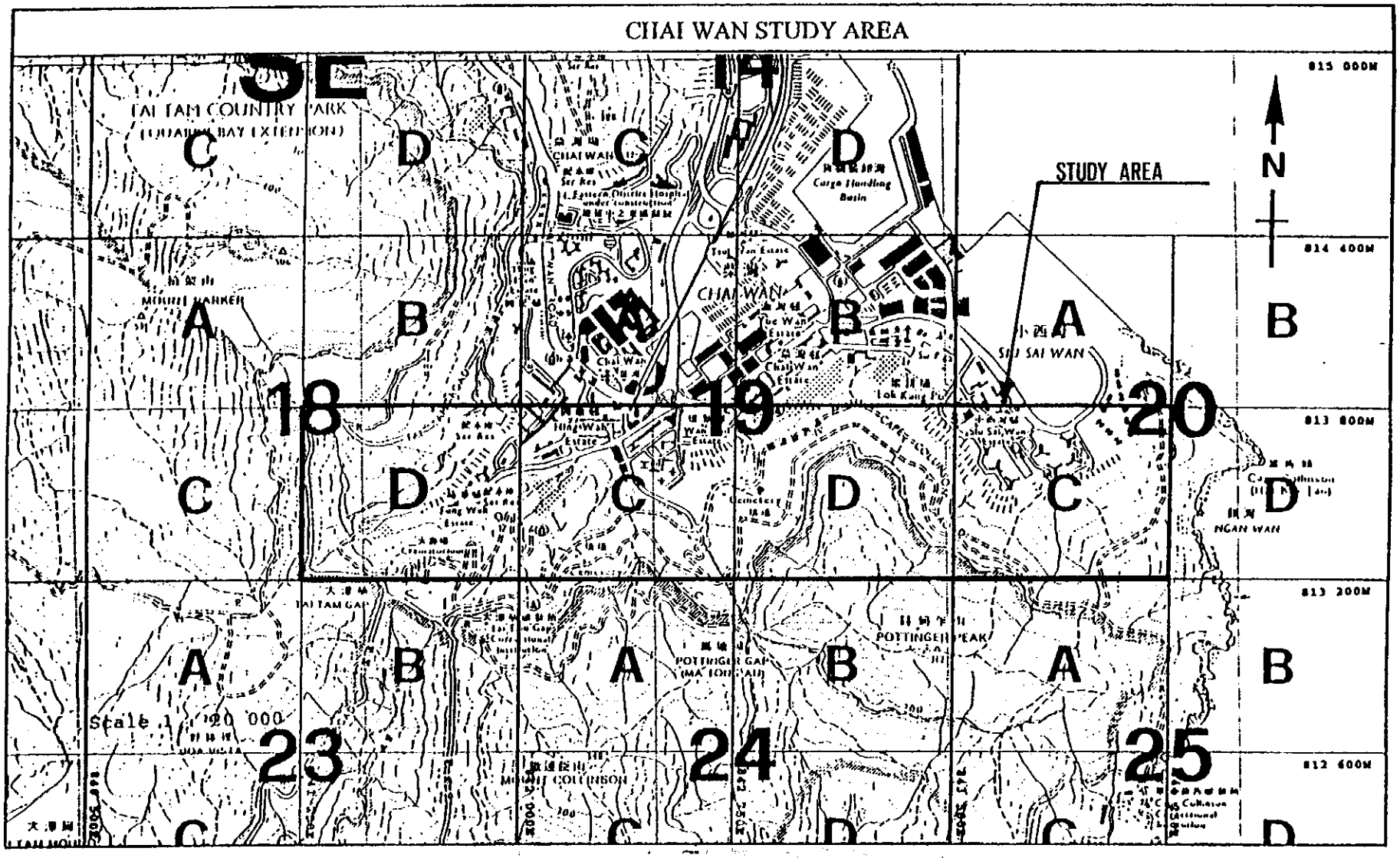

Figure 1 - The Chai Wan Study Area

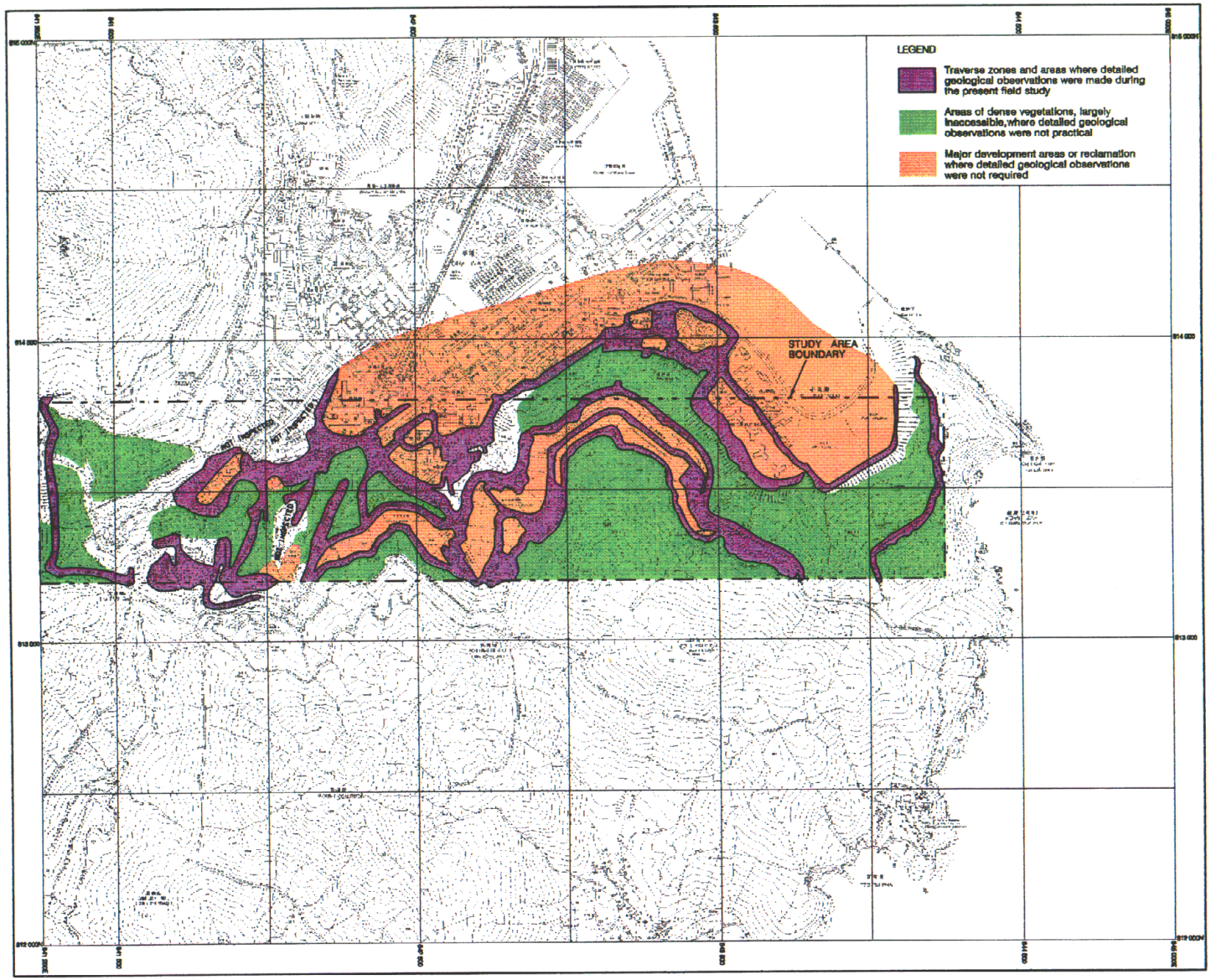

Figure 2 - Traverses Undertaken and Other Areas Surveyed as Part of the Geological Field Investigation of the Chai Wan Study Area

Quaternary Superficial Deposits

Qb	Beach deposits
Qa	Alluvium
Qd	Debris flow deposits
HHH	Hang Hau Formation
ms	Marine sand

Mesozoic Volcanic Rocks

JAC	Ap Lei Chau Formation
JSM	Shing Mun Formation
e	Eutaxite
tb	Tuff breccia

Intrusive Igneous Rocks

gf	Fine-grained granite
gfm	Fine-to medium-grained granite
sqm	Quartz syenite
b	Basalt
ap	Aplite

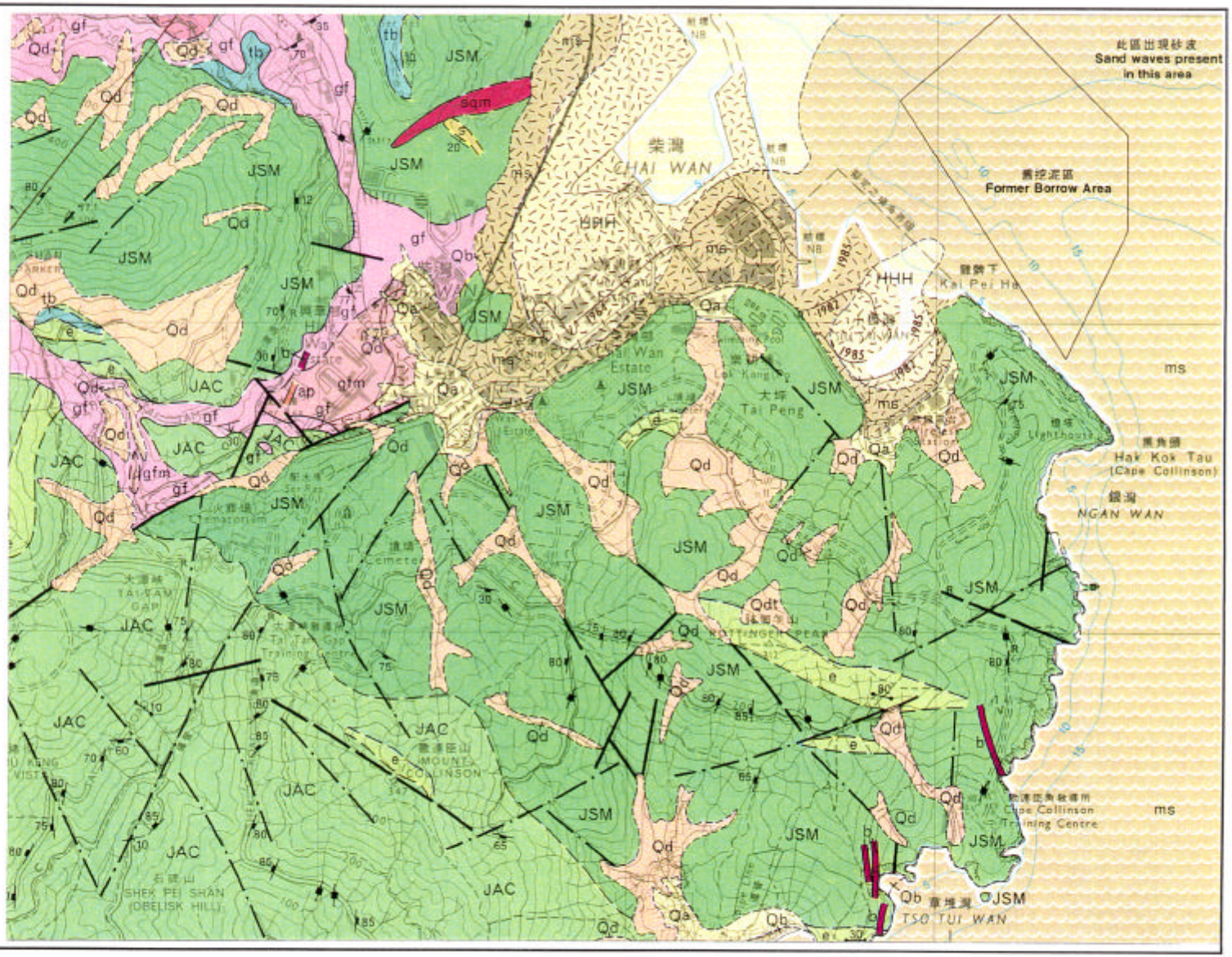

Figure 3 - Hong Kong & Kowloon : Solid and Superficial Geology (Sheet 11, Scale 1 : 20 000; GCO, 1986)

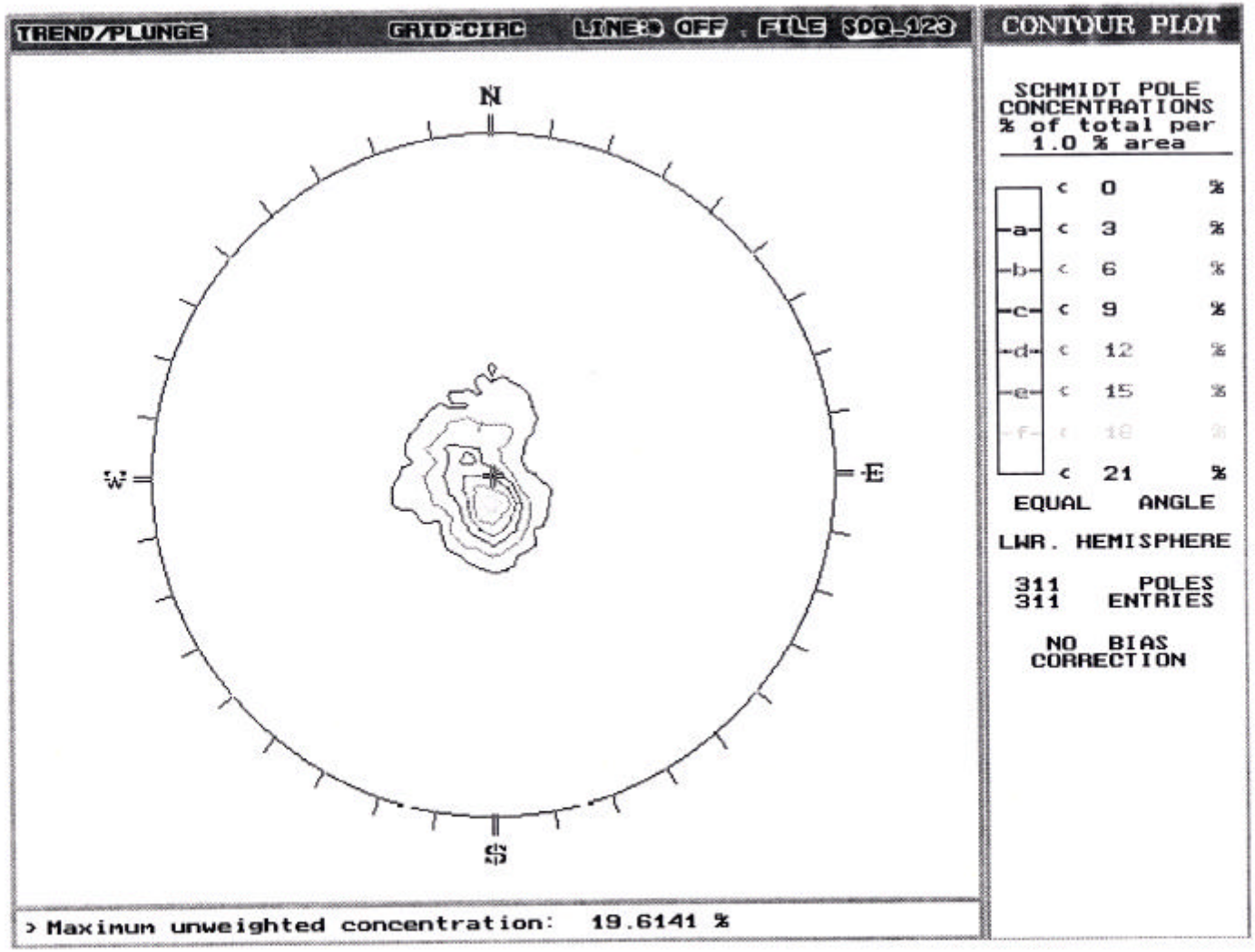

Figure 4 - Contoured Stereoplot (Lower Hemisphere) of Poles to Primary Volcanic Rock Fabrics, Mainly Including Eutaxitic Fabrics, from the Chai Wan Study Area Shown on Map No. 2

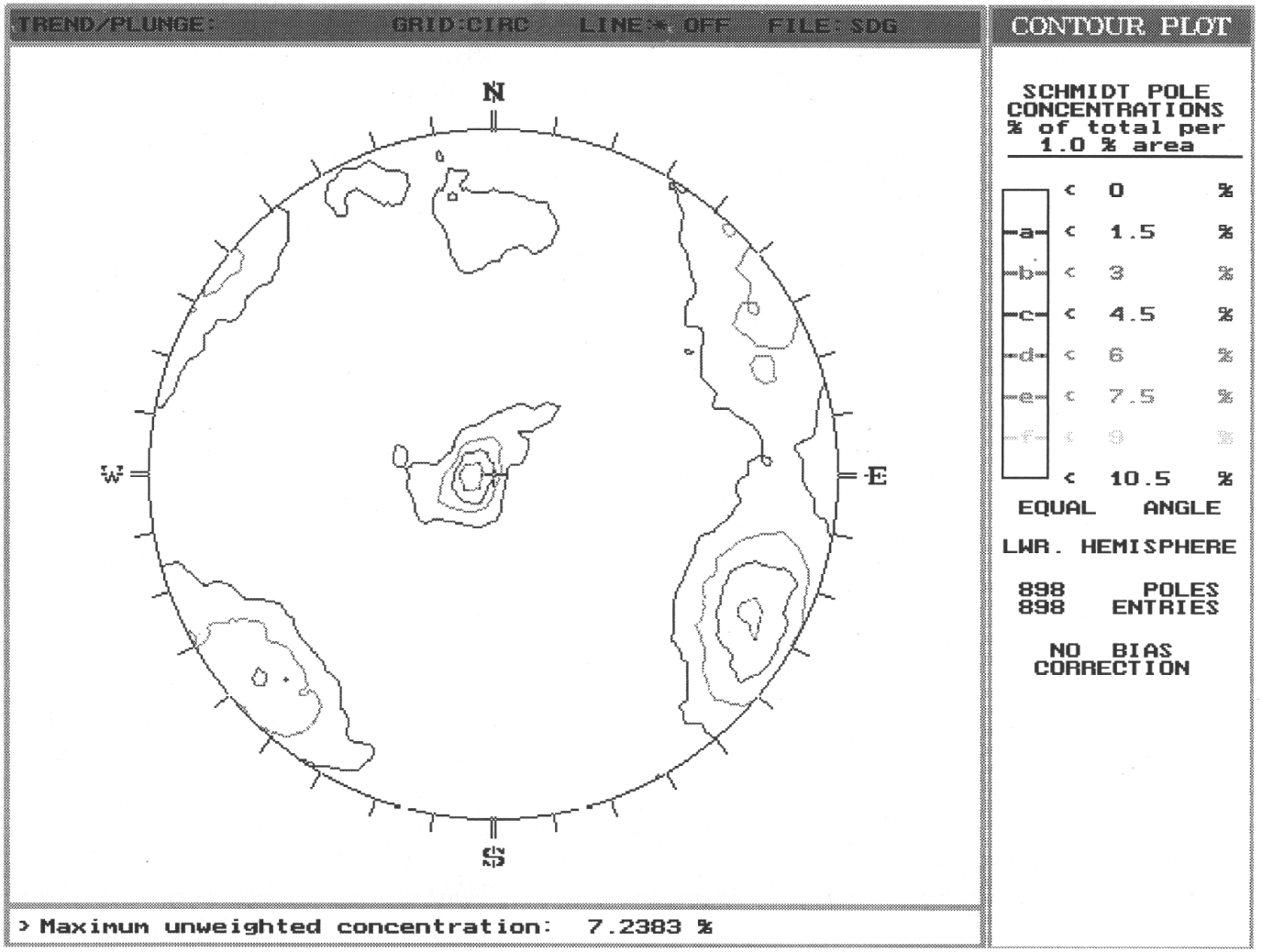

Figure 5 - Contoured Stereoplot (Lower Hemisphere) of Poles to Joints, from the Chai Wan Study Area Shown on Map No. 2

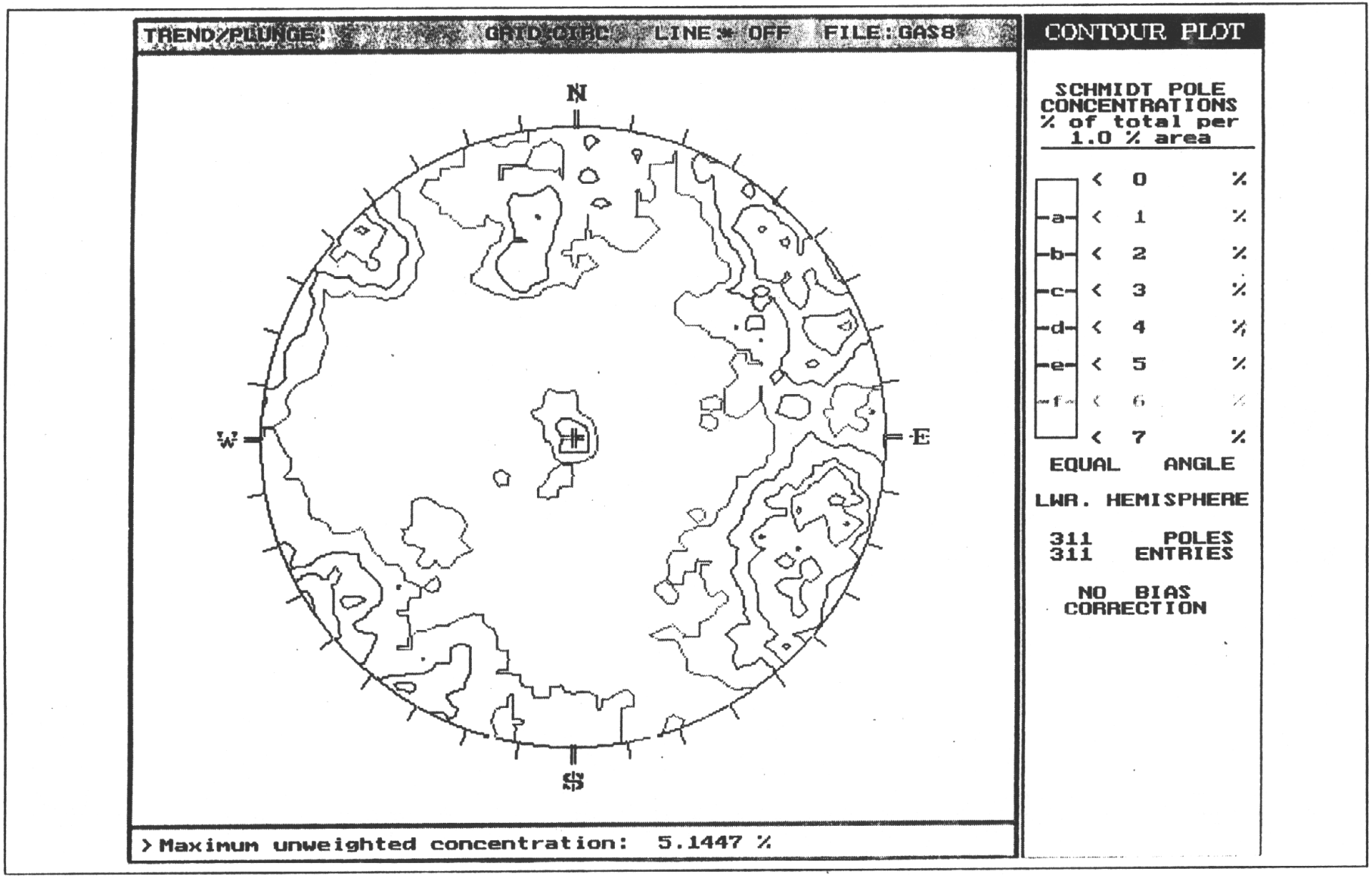

Figure 6 - Contoured Stereoplot (Lower Hemisphere) of Poles to Joints (Primary Joint Data Taken from the GAS 8 Report - Geotechnical Area Study, Chai Wan (GCO, 1981) for the Area Shown on Map No. 5)

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(Taken 24/6/96)

Plate 2 - Typical Volcanic Fabric with Aligned Lapilli and Fine Eutaxitic Foliation (844500 813614) in Slope 11SE-D/C181, Southeast of Siu Sai Wan Estate (Taken 26/6/96)

Plate 3 - General View of Planar, Obliquely Outward-dipping PW0/30 andPW90/100 Rock Mass Weathering Zone Interface (84356 81362), Associated with Kaolinitic Clay Development, in Slope 11SE-D/C188, West of Siu Sai Wan Estate (Taken 17/7/96)

Plate 4 - Low-level Oblique View to the West, of Slope 11SE-D/C188, on the West Side of Siu Sai Wan Estate, Showing the PW0/30 and PW90/100 Rock Mass Weathering Zone Interface, and Associated with Seepage and Kaolinitic Clay Development (Taken 2/7/96)

Plate 5 - High-level Oblique View to the West, of Slope 11SE-D/C188 on the West Side of Siu Sai Wan Estate, Showing the PW0/30 and PW90/100 Rock Mass Weathering Zone Interface, and Associated with Seepage and Kaolinitic Clay Development (Taken 2/7/96)

Plate 6 - General View of Outward-dipping, Planar PW0/30 and PW90/100 Rock Mass Weathering Zone Interface (843478 813884), Associated with Kaolinitic Clay Development, in Slope 11SE-D/C187, Northwest of Siu Sai Wan Estate (Taken 24/7/96)

Plate 7 - Close-up of Exposure Shown in Plate 6, Showing Kaolinitic ClayDevelopment along the Outward-dipping, Planar PW0/30 and PW90/100 Rock Mass Weathering Zone Interface (843478 813884), Slope 11SE-D/C187, Northwest of Siu Sai Wan Estate (Taken 24/7/96)

Plate 8 - General View of Outward-dipping, Planar PW0/30 and PW90/100 Rock Mass Weathering Zone Interface (843510 813932), Associated with Kaolinitic Clay Development, Slope 11SE-D/C187, Northwest of Siu Sai Wan Estate (Taken 24/7/96)

Plate 9 - Close-up of Exposure Shown in Plate 8, Showing Kaolinitic ClayDeveloped along Outward-dipping, Planar, PW0/30 and PW90/100 Rock Mass Weathering Zone Interface (843510 813932), Slope 11SE-D/C187, Northwest of Siu Sai Wan Estate (Taken 24/7/96)

Plate 10 - General View To South, of the PW0/30 Zone Containing the Kaolinitic Clay-infilled Joint Shown in Plate 11, with Occasional, Large, Joint-bounded Cores Comprising Tuff, Predominantly of Weathering Grade II (Taken 24/7/96)

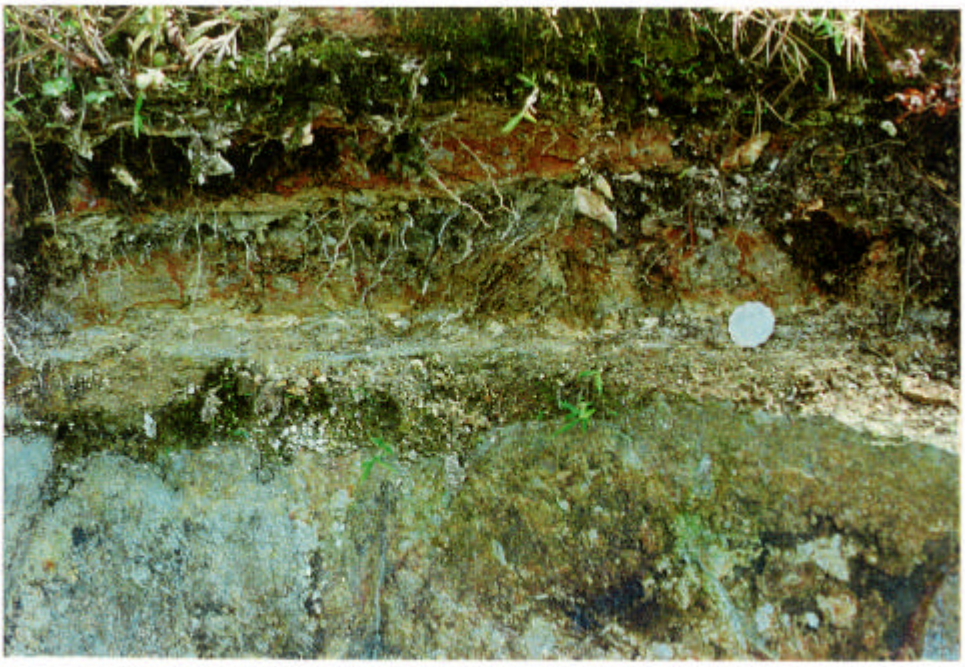


Plate 11 - White Kaolinitic Clay Vein (c.10 mm) Infilling a Shallowly-inclined Joint (843582 813586), Dipping Directly Outward within the PW0/30 Zone in Slope 11SE-D/C188, West of Siu Sai Wan Estate (Taken24/7/96)

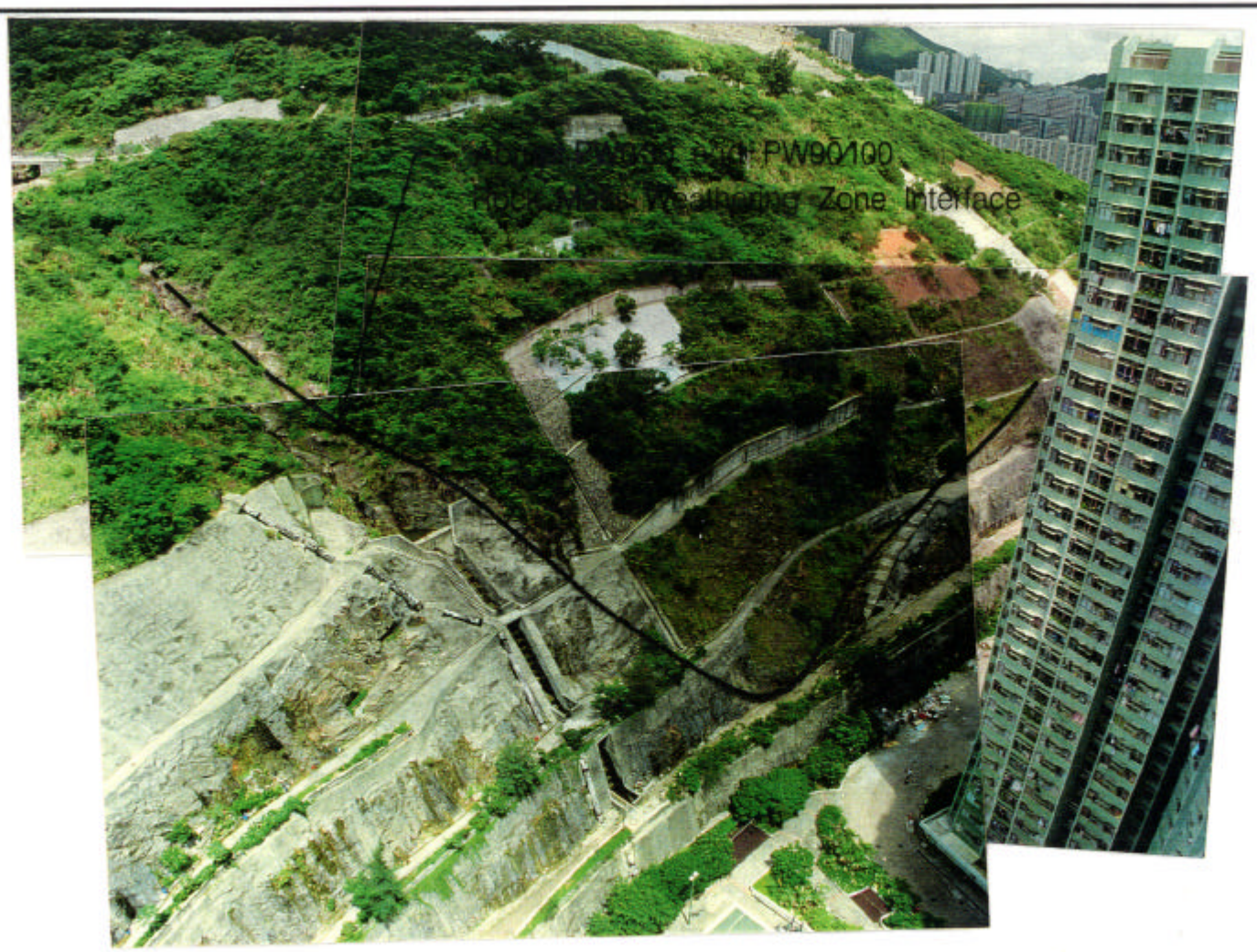


Plate 12 - High-level Oblique View to Northwest, of Slope 11SE-D/C188 on the West Side of Siu Sai Wan Estate, Showing Pronounced Local Variation in the Depth of Weathering (Taken 2/7/96)

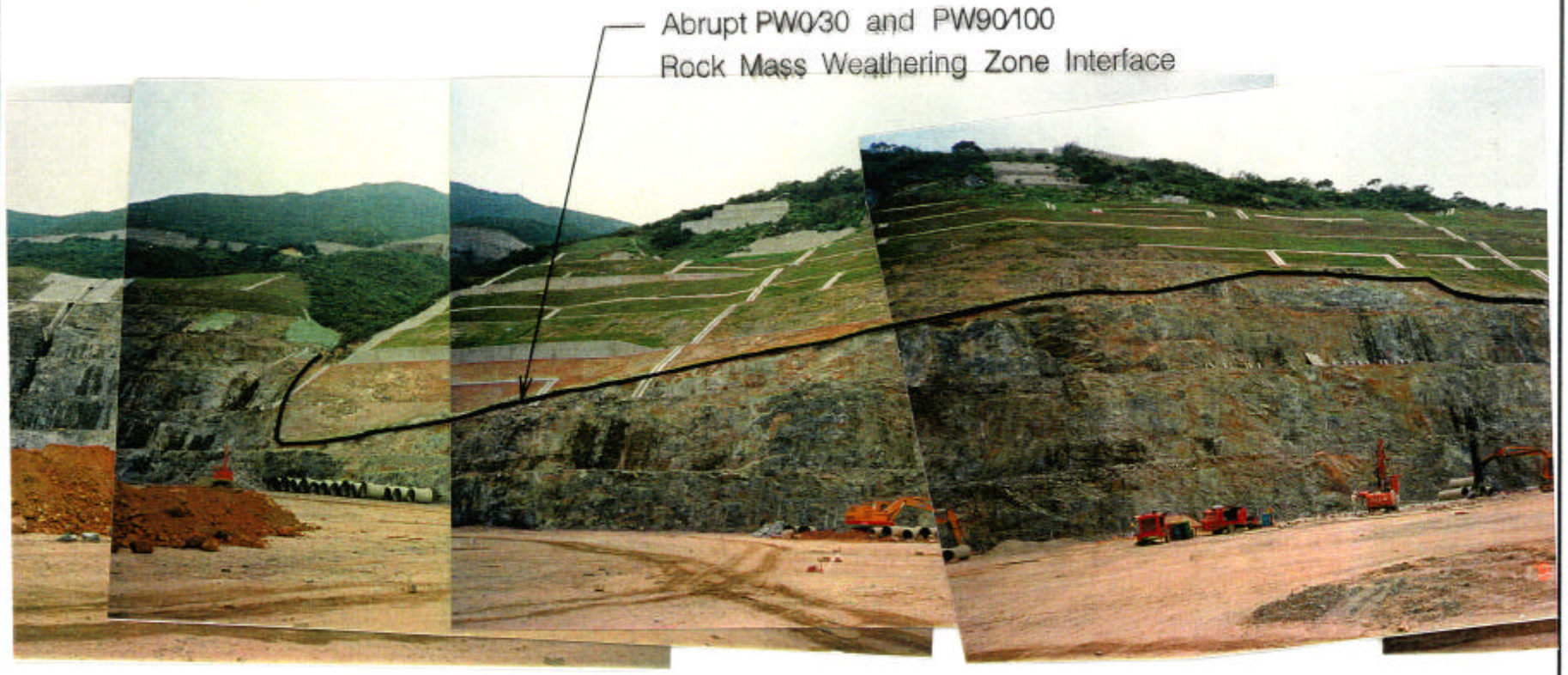


Plate 13 - View to the West, of Slope 11SE-D/C188 During Development, Showing Variable Weathering Depth, Related to Faulting, and the Generally Planar PW0/30 and PW90/100 Rock Mass Weathering Zone Interface (from f.69 in GCI 3/2/105; Taken 28/4/87)

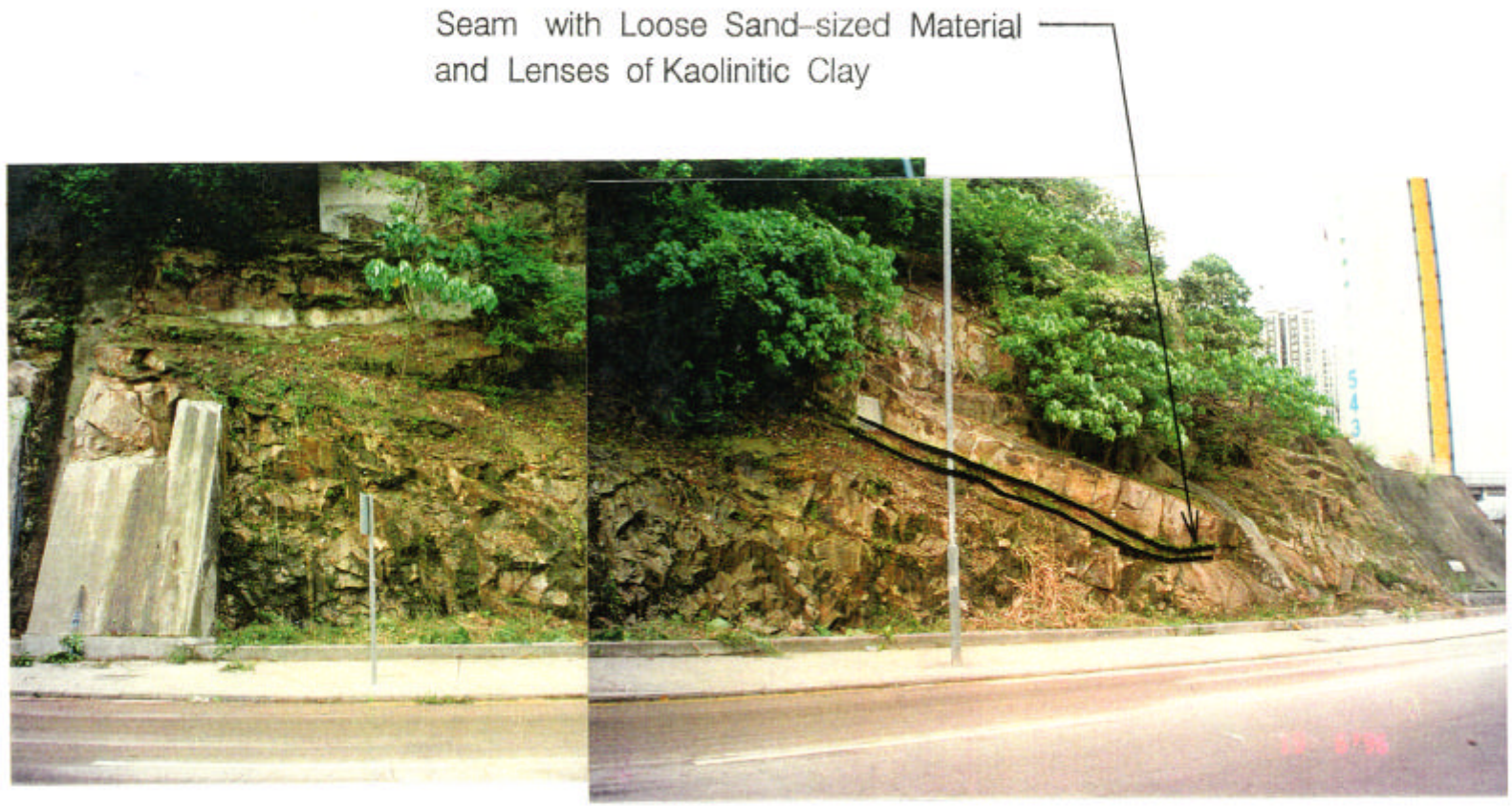


Plate 14 - General View Northeast, of Slope 11SE-D/C49 in Fine- to Medium-grained Granite, on the Northwest Side of Wan Tsui Road. Shallowly-inclined, Obliquely Outward-dipping Seams Occur Containing Loose Sand-Sized Material and White Kaolinitic Clay Lenses. Extensive Seepage was Observed from Some Seams (Taken 19/6/96)

Plate 15 - Close-up of Slope 11SE-D/C49, as in Plate 14, Showing Foliation in the Seams, in Contrast to the Predominantly Grade II to III Rock Bounding the Seams. Incipient Movement along the Margins of the Seam is Shown by Detachment on Steeply-inclined Joints in Rock above the Seam in the Upper Part of the Plate (Taken 19/6/96)

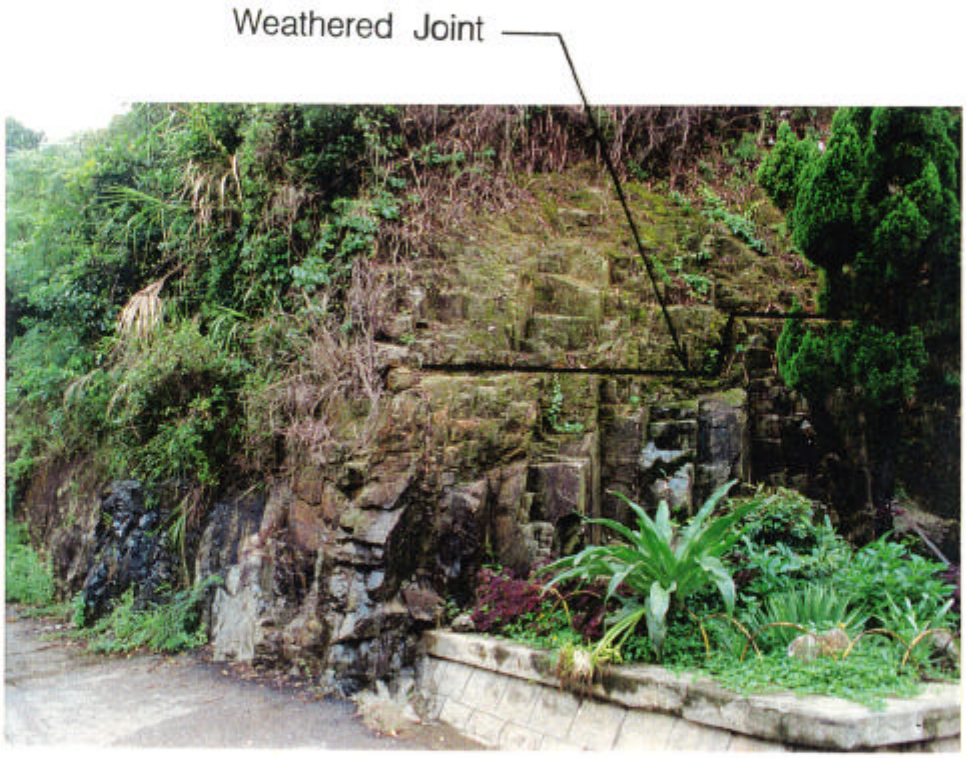


Plate 16 - A Wide, Weathered, Shallowly-inclined Joint in Slope 11SE-D/C98, West Side of Cape Collinson Road. The Joint Infill is of CompletelyDecomposed Tuff and Kaolinitic Clay. The Joint Locally Steps and Bifurcates across Subvertical Joints (Taken 15/7/96)

Plate 17 - Prominent Weathering of Tuff (843435 813785) along a Moderately Wide, Shallowly-inclined Joint, Dipping into the Slope, at the North End of Slope 11SE-D/C188, West of Siu Sai Wan (Taken 12/7/96)

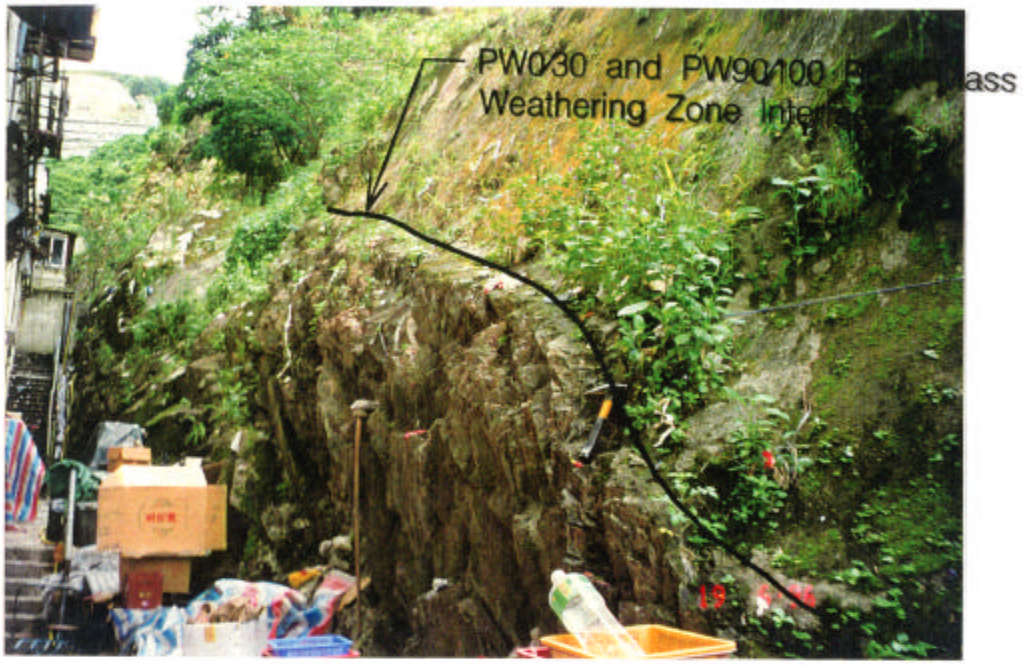


Plate 18 - Planar Interface in Tuff, Separating the PW90/100 and PW0/30 Zones, Looking South at Slope 11SE-D/C14, South of Fei Tsui Road (Taken 5/7/96)

Plate 19 - Oblique View of Slope 11SE-D/C41, Looking Southwest, on the South Side of Fei Tsui Road, Showing Concavity in the Shotcreted Slope Approximately Coinciding with the Outward-dipping PW0/30 and PW90/100 Rock Mass Weathering Zone Interface. Eutaxitic Fabric also Dips Outward in Exposed Rock near the Slope Base (Taken 5/7/96)

Plate 20 - Seepage from Weepholes in Shotcreted Slope 11SE-D/C17 on theSoutheast Side of San Ha Street. Several Small Landslides (Map No. 3)have Occurred along this Slope which is a Modification of the Pre-reclamation Cliff Line (Taken 19/6/96)

Plate 21 - Extensive Seepage from Shallowly-inclined Joint (84430 813690)Dipping Outward from Slope 11SE-D/C181, Southeast of Siu Sai WanEstate (Taken 26/6/96)

APPENDIX 1

AERIAL PHOTOGRAPHS USED IN THE API STUDY

AERIAL PHOTOGRAPHS USED IN THE API STUDY

Year	Aerial Photograph Numbers
1949	Y1335-45
1961	Y4759-61
1963	Y7135-48;Y7196-7209;Y7282-94
1967	Y13286-9
1972	2289-91
1976	23748-53; 23775-83
1982	43019-30
1989	A17811-16; A17856-9
1993	A30977-82; A30993-8
1994	CN8068-73
1995	CN12741-7

Relevant features were drawn onto 1:1 000 topographic maps using the symbols listed in Table 1. These features were then digitised and a 1:5 000 scale compilation made for the entire study area.

APPENDIX 2

SEEPAGES OBSERVED DURING SURVEY

SEEPAGES OBSERVED DURING THE STUDY

The most significant examples of seepage noted during the field survey were in the following slopes:

(a) 11SE-D/C18 (behind Block 15 on the southeast side of San Ha Street) from a laterally extensive series of weepholes, 2m up from the base of the chunam slope.
(b) 11SE-D/C17 on the southeast side of San Ha Street from several weepholes towards the western end of the shotcrete slope (Plate 20).
(c) 11SE-DC23 at several locations along the pre-reclamation cliff line on the southwest side of Chai Wan Road, the seepage appearing to come mainly from a level largely covered by vegetation, several metres up the slope and possibly coinciding with the PW0/30 and PW90/100 rock mass weathering zone interface.
(d) 11SE-D/C49 on the northwest side of Wan Tsui Road mainly in association with shallowly inclined, highly weathered and foliated joints most of which daylight at an oblique angle to the cut slope (Plate 14). Extensive seepage was also noted from the approximate level of the PW0/30 and PW90/100 rock mass weathering zone interface and from steeply-inclined micaceous shear zones towards the southwest end of the slope.
(e) 11SE-D/C41 on the southeast side of Fei Tsui Road, at several locations approximately 2 m above the base of the mainly shotcreted slope, which approximately coincides with the level interpreted to be that of PW0/30 and PW90/100 rock mass weathering zone interface (Plate 19).
(f) 11SE-D/C/188 & 189 on the southwest and south sides of the Siu Sai Wan Housing Estate (Plates 4 & 5). Seepage was noted in conjunction with many shallowly-inclined joints that daylight directly or more typically at an oblique angle to the cut slope within rock (grade II mainly). Gently concave-upward joints of these orientations were particularly noted for seepage. Seepage was also common at the level of the abrupt weathering front transition from rock to soil, with maximum seepage occurring where the transition was a concave-upward depression as to the southwest of Sui Luk House.(g)11SE-D/C181 on the southeast side of the Siu Sai Wan Housing Estate where seepage was locally strong from shallowly-inclined joints dipping directly out of the slope (Plate 21).
(h) 11SE-D/C182 & 183 on the eastern side of the Siu Sai Wan Housing Estate where continuous flow was seen from a series of weepholes in the recently reconstructed retaining wall.
(i) 11SE-D/C138 on the west side of Tai Tam Road where continuous flow was noted immediately to the south of a landslide scar.

APPENDIX 3

RELATIONSHIPS OF VOLCANIC FABRICS TO CUT SLOPES IN THE CHAI WAN STUDY AREA

RELATIONSHIPS OF VOLCANIC FABRICS TO CUT SLOPES IN THE CHAI WAN AREA

3A - Slopes in which the primary volcanic fabric was observed to dip adversely, either directly out of the slope, or at a high angle to its strike include:

(a) 11SE-D/C41 (Plate 19) on the southeast side of Fei Tsui Road. The orientation of the fabric also approximately coincides with the orientation of the PW0/30 and PW90/100 rock mass weathering zone interface within the slope.
(b) The southeasterly extension of, and possibly the northeast face of slope 11SE-D/C195 at the rear of the Roman Catholic Cemetery.
(c) Obliquely outwards from slope 11SE-D/C 199 on the southern side of Cape Collinson Road.
(d) The western part of slope 11SE-D/C18 and possibly the eastern part of slope 11SE-D/C17 (Plate 20) on the southeast side of San Ha Street.
(e) 11SE-D/C20 & 19 where the fabric dips obliquely out of the slope albeit at a very shallow angle (mainly 0-7°, locally up to 15°) on the south and southeast side of San Ha Street.
(f) Locally within slope 11SE-D/C188 (Plates 4 & 5), and especially towards its northern end, on the west side of the Siu Sai Wan Housing Estate.
(g) Within several small, unregistered cut slopes at the top of the Chinese Permanent Cemetery, to the northeast and east of Pottinger Peak (c.84316 81368).
(h) Within small unregistered cut slopes along Cape Collinson Road on the northeast side of the Chinese Permanent Cemetery.
(i) In the northwest part of 11SE-D/C190 within the Siu Sai Wan Housing Estate.

3B - Slopes in which the primary volcanic fabric was inferred from the orientation of volcanic fabric form lines to dip adversely, either directly out of the slope, or at a high angle to its strike include:

(a) 11SE-D/C 195 & 196 above the Roman Catholic Cemetery, and slopes 11SE-D/C 128, 129, 297, 193 & 194 within and below it.
(b) 11SE-D/C 39 and possibly 11SE-D/C13 on the southwest side of Lin Shing Road, and 11SE-D/C163 on the northeast side of the same road.
(c) 11SE-D/C124 on the southwest side of Cape Collinson Road.
(d) 11SE-D/C270 on the southwest side of Cape Collinson Road.
(e) 11SE-D/CR168, 169, 170 & 171 within the school grounds on the south side San Ha Street, and obliquely behind the southern portion of the retaining wall 11SE-D/R51 in the adjoining school to the east.
(f) Possibly with a slightly oblique outward component of dip, or directly outward behind retaining wall 11SE-D/R7 on the south side of Artview Court and possibly more obliquely behind retaining wall 11SE-D/R27 on the south side of Wah Yu Court and the adjoining unregistered retaining wall behind Fu Ming Court to the west.
(g) Locally obliquely outward with respect to slope 11SE-D/C187 on the northwest side of the Siu Sai Wan Housing Estate.
(h) 11SE-D/C208 behind the Water Service Reservoir southwest of Siu Sai Wan [this slope was not examined during the survey].

APPENDIX 4

SUMMARY OF INFORMATION REVIEWED FOR THE ENGINEERING GEOLOGY ASSESSMENT

Appendix 4A - Landslip Incident Reports

Year	Report Number	Remarks
1995	HK95/7/6	No Photographs - damaged chunam.
	HK95/8/43	Fei Tsui Road Landslip.
1994	HK94/8/23	No photographs.
1993	HK93/9/11	No photographs - 40m³ rock fall.
	HK93/6/23	No photographs - small failure in cut slope.
	HK93/9/12	No photographs - 5m³ failure in weathered rock.
	HK93/9/13	No photographs.
	HK93/6/22	No photographs - rock fall.
	HK93/6/9	Landslide card - 150m³ - shallow failure.
1992	HK92/5/19	No photographs.
	HK92/5/17	No photographs.
	HK92/1/1	No photographs - failure in soil cut slope.
	HK92/5/11	Shallow failure in residual soil.
	HK92/5/41	Retaining wall and fill platform failure.
	HK92/5/12	Failure on relict joints - clay on surface.
	HK92/5/108	Shallow failure in colluvium and grade V tuff.
	HK92/5/107	Boulder fall.
	HK92/5/202	Soil cut slope - colluvium and soil pipe noted.
	HK92/5/91	Not inspected by GEO.
1991	HK91/7/1	Failure in rock cut slope.
	HK91/10/2	No photographs.
	HK91/1/1	No photographs.
1990	HK90/3/1	Chunam blow out - no photographs.
1989	HK89/5/18	Landslide card - 550m³ - low angle release surface.
	HK89/9/1	Very minor failure.
1988	HK88/7/8	No photographs.
	HK88/8/2	Retaining wall failure - no photographs.
1987	HK87/5/10	Landslide card - 70m³ - joint controlled failure.
	HK87/11/2	Erosion on slope - no photographs.
	HK87/7/17	Toppling failure - rock cut slope.
	HK87/6/1	Retaining wall failure - no photographs.
	HK87/3/14	Retaining wall failure - no photographs.
	HK87/7/2	Retaining wall failure - no photographs.
1985	HK85/9/11	No photographs - shallow failure.
1983	6/25/83	Missing.
	6/33/83	Missing.
1982	5/11SE-D	Landslide card - shallow slide.
	H29/82	Minor landslip.
	H64/82	Washout.
	H30/82	No photographs.
1981	6/81	Missing.

Appendix 4B - Binnie & Partners - Slope Catalogue 1977-78

Sheet Number	Feature Number
11SE-18D	11SE-D/C46
	11SE-D/C59
	11SE-D/C60
	11SE-D/C63
	11SE-D/C71
	11SE-D/C120
	11SE-D/C132
	11SE-D/C135
	11SE-D/C136
	11SE-D/C137
	11SE-D/C138
	11SE-D/C140
	11SE-D/C150
	11SE-D/C159
	11SE-D/C164
	11SE-D/C166
	11SE-D/CR61
11SE-19C	11SE-D/C12
	11SE-D/C13
	11SE-D/C14
	11SE-D/C15
	11SE-D/C16
	11SE-D/C36
	11SE-D/C39
	11SE-D/C41
	11SE-D/C42
	11SE-D/C50
	11SE-D/C70
	11SE-D/C84
	11SE-D/C99
	11SE-D/C100
	11SE-D/C124
	11SE-D/C125
	11SE-D/C127
	11SE-D/C128
	11SE-D/C129
	11SE-D/C130
	11SE-D/C163
11SE-19D	11SE-D/C89
	11SE-D/C88
	11SE-D/C97
	11SE-D/C98
	11SE-D/C139
11SE-20C	11SE-D/C24
	11SE-D/C90

Appendix 4C - Ground Investigation Reports (Sheet 1 of 2)

Report No.	Contract No.	Works Order No.	Contract Title	No. of Boreholes
513	-	-	Site Investigation: Slope No. 11SE 19C1	3
1487	-	-	Chai Wan Chinese Permanent Cemetary	12
1574	-	-	Hing Wah R.E., Chai Wan	24
1579	-	-	Hing Wah Resettlement Estate, Chai Wan	13
1873	-	-	Slope below Cape Collinson Road	3
2446	-	Q7 / 2 / 1.80	Site Investigation: Tai Tam Road	12
2806	416 / 79	-	Landslide Study, Site Investigation Site: Cape Collinson Road, Slope No.11SE-D/F1	1
2807	416 / 79	-	Landslide Study Site Investigation: Site: Chai Wan Estate, Slope No. 11SE-D/FR4	1
2998	-	-	Redevelopment of Chai Wan (W) Estate	28
3333	402 / 81	Q7 / 2 / 6.9	Site Investigation: Hong Kong and Kowloon Site:Feasibility Study Siu Chai Wan Development	14
3448	402 / 81	Q7 / 2 / 6.49	Site Investigation: Hong Kong and Kowloon Site: Cape Collinson Road, Country Park	12
4503	2 / GCO / 1983	Q7 / 2 / 9.4	Extension to Columbarium at Cape Collinson, Crematourium Stage VI	4
4530	98 OF 1981	106	Wan Tsui Estate, Chai Wan Phase 3	31
4531	98 OF 1981	142	Chai Wan Estate - Slope 11SE-D/C18	5
5089	389 / 38	-	Redevelopment of Chai Wan (W) Estate	28
5807	98 OF 1981	182	Wan Tsui Estate, Chai Wan, HK	21
6527	2 / GCO / 83	Q7 / 2 / 09.63	Site Investigation: Improvement of Shel O Water Supply	6
6891	433 / 80	-	Site Investigation Stage 2 and 3, detailed study of slopes and retaining walls Site: Hing Wah Estate, Slope No. 11SE-D/C34 & C49	3
6963	CEQ5 / 85	-	Site Investigation: Chai Wan 'C' (Fieldwork Report: Volume II)	-
7057	3 OF 1985	54	Site Investigation: Chai Wan 'C' (Fieldwork Report: Volume I)	10
7058	3 OF 1985	54	Site Investigation: Chai Wan 'C' (Fieldwork Report: Volume II)	9
8255	3 OF 1985	125	Site Investigation: Chai Wan 'C'	23
8256	3 OF 1985	126	Site Investigation: Chai Wan 'C'	23

Appendix 4C - Ground Investigation Reports (Sheet 2 of 2)

Report No.	Contract No.	Works Order No.	Contract Title	No. of Boreholes
8316	GC / 85 / 02	PW7 / 2 / 13.195	Site Investigation: Item No. 072BF in Category AB of Public Works Programme. Title: Fire Services R & F Quarters, Chai Wan	5
8725	GC / 85 / 02	PW7 / 2 / 13.172	Site Investigation: Stage 2 Study, Slope No. 11SE-D/C 14 Behind No. 4 - 32 Lin Shing Road, Chai Wan	3
8796	3 OF 1985	204	Site Investigation: Siu Sai Wan Phase 1	47
10403	197 OF 1985	258	Site Formation & Associated Works For Chai Wan 'C'	27
11734	GC / 87 / 02	PW7 / 2 / 19.125	Site Investigation: Water supply to Siu Sai Wan Development	6
16884	122 OF 1990	104	HK 16RR Hing Wah Redevelopment PH.1	5
17404	GC / 91 05	PW7 / 2 / 33.152	Ground Investigation: Slope No. 11SWE - D/F1 Cape Collinson Road	1
18343	122 OF 1990	M28	Proposed new escalator and new food centre in Wan Tsui Estate	4
18381	122 OF 1990	M52	Stage 2 study 11SE - D/R10, Hing Wah Estate	1
20716	91 OF 1992	94	Redevelopment of Hing Wah Estate PH.1	34
20723	91 OF 1992	100	Hing Wah Estate PH.1 Redevelopment	22
20804	91 OF 1992	180	Wan Tsui Estate Redevelopment	14
20869	91 OF 1992	250	Wan Tsui Infill Site	6
20888	91 OF 1992	277	Hing Wah Estate PH.1 Redevelopment	10
20954	91 OF 1992	M69	Siu Sai Wan Estate - Landslip Study	2
21153	91 OF 1992	314	Wan Tsui Estate Redevelopment - Slope Study, Slope No. 11SE-D/CR163, F7, F70 and Slope N	12
21351	GE / 93 / 11	GE / 93 / 11SA.10	Cape Collinson Road Ground Investigation	2
21517	GE / 95 / 03	GE / 95 / 03.11C	Investigation, Design, and Construction of Slope Stabilization Works to Slope No. 11SE-D/ C42 at Fei Tsui Road (Fieldwork Report: Volume 1 of 2)	5
21518	GE / 95 / 03	GE / 95 / 03.11C	Investigation, Design, and Construction of Slope Stabilization Works to Slope No. 11SE-D/ C42 at Fei Tsui Road (Fieldwork Report: Volume 2 of 2)	5
21643	GE / 95 / 06	GE / 95 / 06.69	Feature No. 11SE-D/ C42, Fei Tsui Road Ground Investigation	0

Appendix 4D - Island Division Files

Type of File	File Ref.	File Title	Remarks
Architectural Office / Department Project File	GCI 3/1/7	Extension to Columbarium at Cape Collinson Stage IV & V.	
	GCI 3/1/39	Hing Wah Housing Estate Slope Stability Works ,Hing Wah Housing Estate,Chai Wan.	Fei Tsui Road Slope - Ove Arup & Partners Report.
	GCI 3/1/106	Cape Collinson Road Park Squatter Area above Chai Wan.	-
	GCI 3/1/368	Fei Tsui Road Open Space , Chai Wan.	-
	GCI 3/1/755	-	File not available.
	GCI 3/1/783	New Service Hall at Cape Collinson Crematorium.	-
Housing Department Project File	GCI 3/2/31	Chai Wan Estate (Maintenance) Chai Wan Road , Chai Wan.	Good photos of slopes around estate in early 1980's.
	GCI 3/2/83	Hing Wah Estate (Maintenance) Wan Tsui Road, Chai Wan.	Photos of slopes around site.
	GCI 3/2/91	Chai Wan Housing Department Staff Quarters , Lin Shing Road ,Chai Wan.	Photo of slope 11SE-D/C 37.
	GCI 3/2/100 Part I	Wan Tsui Estate Phase III.	Good photos of slope construction in progress. Irregular weathered seams noted in correspondence at f(97). Photo of sub-horizontal seam which has been scoured out - step in seam noted in photo at f(96) (23/1/85). Slope location not determined. HKHA - S3S, Chai Wan Estate Slope 11SE - D/C18.
	GCI 3/2/100 Part II	GAS Reports Wan Tsui Redevelopment Scheme, Chai Wan (W) Estate Re-development .	-
	GCI 3/2/105	Siu Chai Wan Home Ownership Scheme.	Good photos of site formation works.
	GCI 3/2/165	-	File not available.
BLD Duplicate File	GCI 3/4/3048/67	Lin Shing Road, Chai Wan - CWIL 27 & 28.	-
	GCI 3/4/3088/80	Cape Collinson Road ,Chai Wan - I.L 7715.	-
	GCI 3/4/3023/83	Cape Collinson Road ,Chai Wan - I.L 7715.	-
	GCI 3/4/3028/83	Cape Collinson Road ,Chai Wan - I.L 7715.	-
	GCI 3/4/3064/85	Proposed Chai Wan Baptist Church - Fei Tsui Road / Siu Man Road.	-
	GCI 3/4/3016/86	Cape Collinson Road ,Chai Wan - I.L 7715.	-
	GCI 3/4/3083/90	Siu Sai Wan - CWIL 146.	-
	GCI 3/4/3025/95	4 , Siu Sai Wan , Chai Wan.	-
Dangerous Hillside Notice File	GCI 3/4/DH251/74/HK	4 - 12 Lin Shing Road , Chai Wan.	Advisory letter on maintenance of 11SE-D/C14.
	GCI 3/4/DH179/83/HK	Cape Collinson Road ,Chai Wan - I.L 7715.	Retaining wall failure - also minor soil slope failure remedial works.
	GCI 3/4/DH310/84/HK	9 - 23 Siu Man Road - CWIL 42 , Moon Wah Building , Chai Wan.	Type 2 Advisory - Slope repair and maintenance. Good photos.
	GCI 3/4/DH119/92/HK	-	File not available.
	GCI 3/4/DH152/92/HK	Cape Collinson Chinese Permanent Cemetery - IL 7715.	Remedial works for failed slope.

Appendix 4E - Reports (Sheet 1 of 3)

Report Type	Title	Reference no.
Stage 1 Study Report	Cut Slope 11SE-D/C42 Sui Man Road	S1 85/79
	Cut Slope 11SE-D/C62 Tai Tam Road, Shek O Road Junction	S1R 91/86
	Cut Slope 11SE-D/C80 below Chong Gene Hang College, Ning Foo Street, Chai Wan	S1 88/79
	Cut Slope 11SE-D/C14 behind no.32 Lin Shing Road, Chai Wan	S1R 49/86
	Cut Slope 11SE-D/C37 behind 32 Lin Shing Road	S1 84/79
	Cut Slope 11SE-D/C34 Hing Wah Estate	S1 7/81
Stage 2 Study Report	Fill Slope 11SE-D/F1 Cape Collinson Road	S2R 17/93
	Cut Slope 11SE-D/C34 & D/C49 Hing Wah Estate, Chai Wan	S2 3/82
	Cut Slope 11SE-D/C14 No. 4-32 Lin Shing Rd. Chai Wan, H.K.	S2R 2/88
Special Project Report	Landslide Studies 1982 Case Study No.1 Chai Wan Road	SPR2/83
	Hong Kong Rainfall and Landslides in 1983	SPR12/94
	Rainfall and Landslides in 1984	SPR2/85
	Hong Kong Rainfall and Landslides in 1984	SPR5/95
	Rainfall and Landslides in 1985	SPR1/86
	Rainfall and Landslides in 1986	SPR1/87
	Rainfall and Landslides in 1987	SPR1/88
	Rainfall and Landslides in 1988	SPR3/89
	Rainfall and Landslides in 1989	SPR2/90
	Rainfall and Landslides in 1990	SPR5/91
	Hong Kong Rainfall and Landslides in 1991	SPR5/92

Appendix 4E - Reports (Sheet 2 of 3)

Report Type	Title	Reference no.
Special Project Report	Hong Kong Rainfall and Landslides in 1992	SPR8/93
	Interim Report On Investigation Of The Failure Of Slopes 11SE-D/C182 & 11SE-D/C183 Siu Sai Wan, Hong Kong	SPR3/93
Landslide Study Phase I	20 Letter Reports Of Binnie & Partners August 1973 to January 1974	HO74
Geotechnical Area Studies Programme	Hong Kong and Kowloon	GASP Report 1
Preliminary Geotechnical Assessment	Rehabilitation Of Tai Tam Road	PGA5/91
	Chai Wan Park Extension UC Package XI Projects	PGA11/86
	Chai Wan Folk Museum And Open Space	PGA2/88
Geotechnical Area Study	Chai Wan	GAS Report 8
Report On The Fei Tsui Road Landslide Of 13 August 1995	Independent Review Of The Investigation By The Geotechnical Engineering Office	Volume 1
Report On The Fei Tsui Road Landslide Of 13 August 1995	Findings Of The Landslide Investigation	Volume 2
Advisory Report	Cut Slopes Stability Assessment & Remedial Measures Proposal Siu Sai Wan Development(II)	ADR9/90
Landslide Study Phase IIC	Report On The Stability Of Slopes In The Chai Wan Area December 1977	

Appendix 4E - Reports (Sheet 3 of 3)

Report Type	Title	Reference no.
SIFT Report	Phase 2 SIFT Pilot Study SIFT 1 Upgrade To SIFT 2 Map Sheet Report 1:1000 Map Sheet Number 11SE-19D	
	Phase 2 SIFT Study Map Sheet Report 1:1000 Map Sheet Number 11SE-19C (including SIFT 1 Upgrade to SIFT 2)	
	Phase 2 SIFT Study SIFT 1 Upgrade to SIFT 2 Map Sheet Report 1:1000 Map Sheet Report Number 11SE-20C	
	Phase 2 SIFT Study Map Sheet Report 1:1000 Map Sheet Number 11SE-18D	

APPENDIX 5

SENSITIVITY ANALYSIS

SENSITIVITY ANALYSIS

5.A Sensitivity Analysis Objective

The objective of the sensitivity analysis was to determine whether the nine slopes which have been identified in the study as potentially having similar engineering geological conditions to those at the Fei Tsui Road landslide site, would fail if those conditions did exist. Once the potential for failure has been established, the necessity for further works on the slopes can be quantified.

5.B Assumptions

The following assumptions have been made in the analysis:

(a) A kaolinitic clay infilled seam dips out of the slope face and controls the basal sliding surface. The slopes in question are known or suspected to have low angle clay-infilled discontinuities.

(b) Sub-vertical joint sets form the back scarp release surface. Two subvertical joint sets generally exist over the study area.

(c) The kaolinitic clay infilled seam occurs at the interface between PW0/30 and PW90/100 rock mass weathering zones. Field observations confirm that kaolin concentrations occur at the PW0/30 and PW90/100 rock mass interface. This simplifies the geometry of the stability problem to the soil cut potion of the slope and the natural or man made platform above the cut slope.

(d) Water pressures form within the sub-vertical joint sets and exert hydrostatic pressure and destabilise the slope. This is a standard plane failure assumption, however, the analysis of the Fei Tsui Road landslide suggested that a combination of perched ground water table and water filled sub-vertical joints triggered the landslide. It is therefore considered conservative if only water filled sub-vertical joints are considered.

(e) Lower bound shear strength parameters for the sliding surface obtained from the Fei Tsui Road landslide investigation ie. friction angle (ϕ) = 22° and cohesion (c) = 0kN/m² are adopted in the analysis and,

(f) Use the graphical stability analysis method for plane failure after Hoek and Bray (1981). The analysis assumes a horizontal surface above the cut portion of the slope. This condition is considered conservative since the disturbing force will be less with a horizontal surface than with an inclined surface but the restoring force is unchanged.

(g) The geological model assumed in the sensitivity analysis is as shown on Figure 5.1.

5.C Analysis

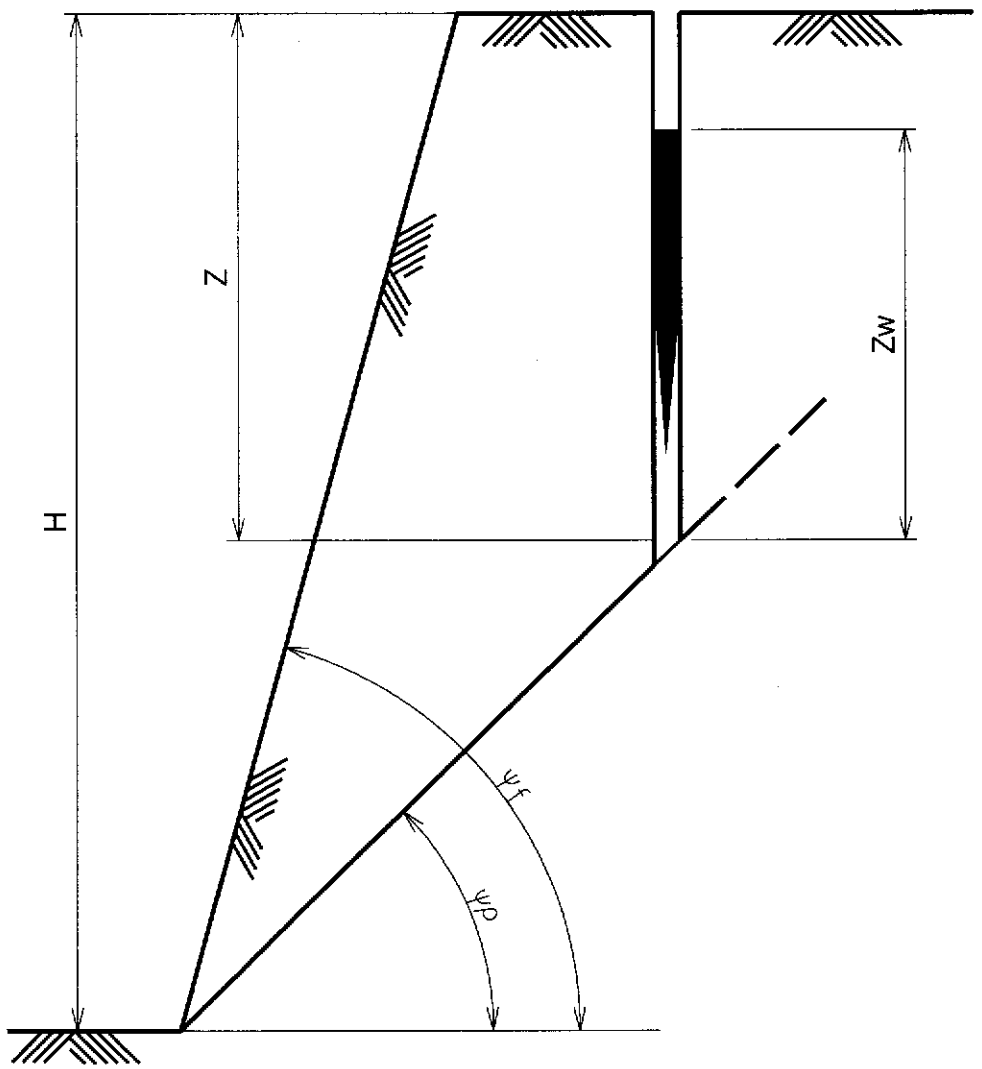
Using the stability equations contained in Hoek and Bray (1981) a spread sheet was constructed to aid the analysis. The following conditions have been analysed:

(a) Factor of safety against instability for a 45° cut soil slope varying the depth of water in the vertical joint for sliding surface inclinations of 10°, 15°, 20°, 25° and 30° (Figure 5.2).

(b) The factor of safety against instability for different combinations of cut slope and sliding surface inclinations assuming a 1m head of water in the vertical joint (Figure 5.3.).

Figure 5.2 demonstrates that the factor of safety drops below unity when the ratio between the depth of water in the joint and the depth of joint is about 0.4 for a sliding surface inclination of 15°. Any sliding surface at a higher inclination is less stable. Figure 5.3. demonstrates that the inclination of the slope surface has very little influence on the stability of the slope.

The above sensitivity analysis demonstrates that plane failure is likely if the Fei Tsui Road landslide conditions exist in the nine slopes. A more complex analysis is therefore not warranted.



H = Slope Height (m)
Z = Depth of Tension Crack (m)
Zw = Depth of Water in Tension Crack (m)
ψf = Slope Face Inclination ( )°
ψp = Sliding Surface Inclination ( )°

Figure 5.1 - Model Used in the Sensitivity Analysis (after Hoek & Bray ,1981)

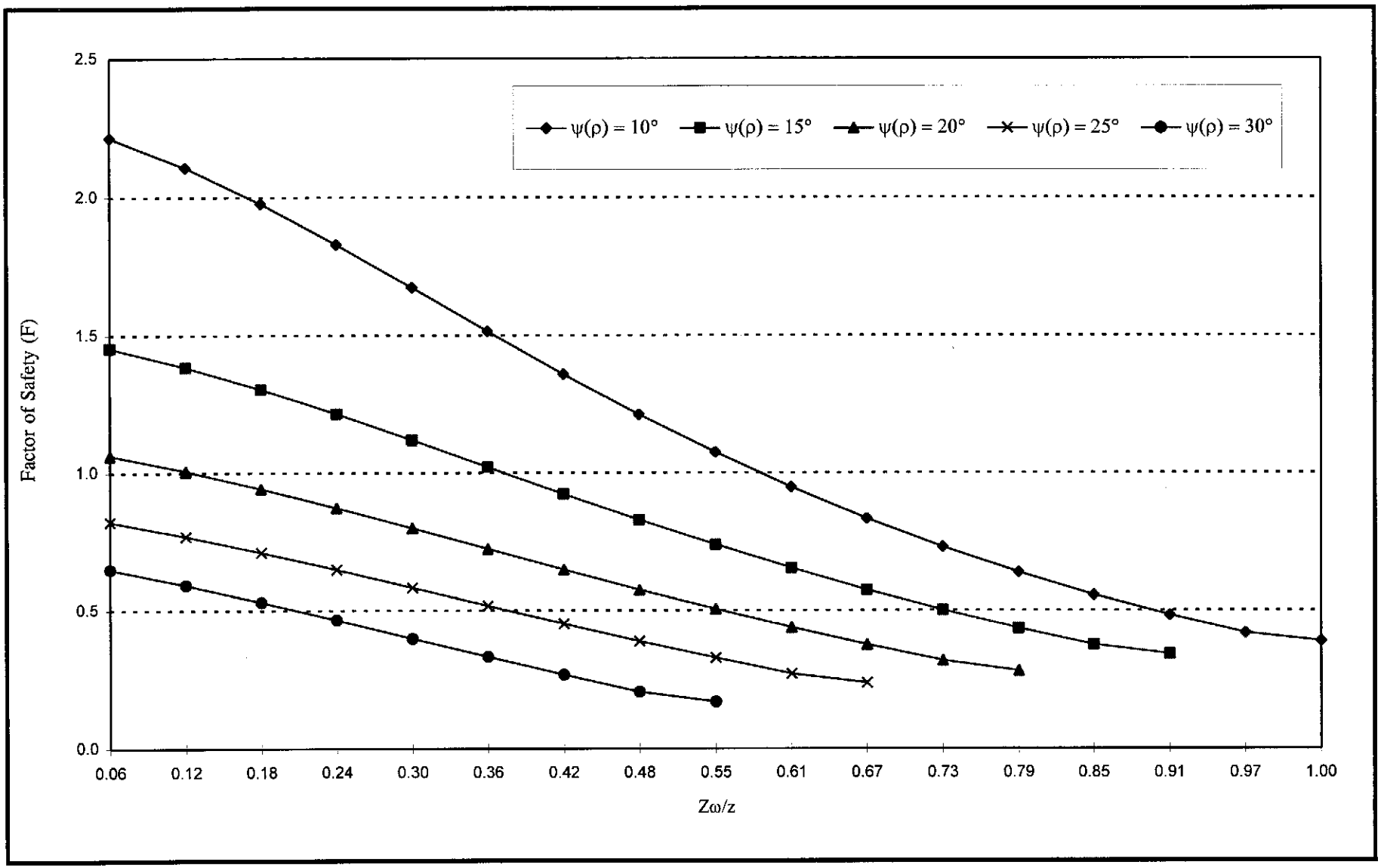


Figure 5.2 - Factor of Safety (F) vs Depth of Water in Tension Crack (Zw)/Depth of Tension Crack (z)

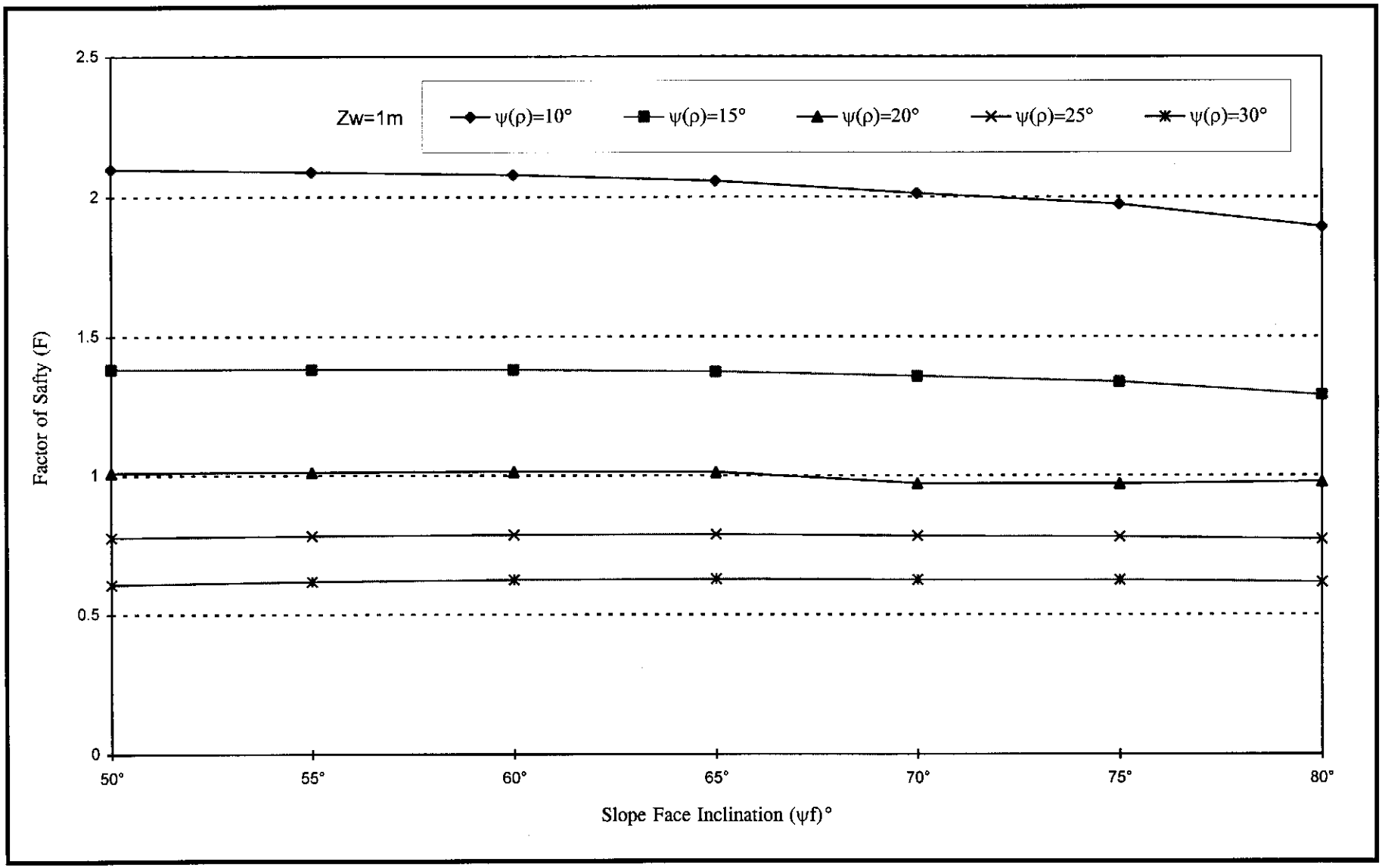


Figure 5.3 - Factor of Safety (F) vs Slope Face Inclination (ψf)° for Various (ψ(ρ))°

LIST OF DRAWINGS
(all at 1:5 000 scale)

Drawing No.	
GS-SP/11-SE-D/758	Map No. 1 - Aerial Photograph Interpretation
GS-SP/11-SE-D/741	Map No. 2 - Geological Fabric and Features
GS-SP/11-SE-D/759	Map No. 3 - Landslide Incidents
GS-SP/11-SE-D/760	Map No. 4 - Ground Investigation
GS-SP/11-SE-D/761	Map No. 5 - Report Summary
GS-SP/11-SE-D/762	Map No. 6 - Seepages and Registered Slopes (Excluding Fill Slopes)