Site Investigation and Geotechnical Engineering Practice in Hong Kong

E. W. Brand & H. B. Phillipson
Geotechnical Control Office, Engineering Development Department, Hong Kong

Synopsis: This Paper reviews site investigation practice in Hong Kong as related to the major geotechnical engineering problems of slope stability and site formation, foundations, deep excavations, reclamation and tunnelling. The heterogeneous residual soils and colluvium pose special problems for site investigation and for engineering design and construction. Fairly sophisticated investigation and testing techniques are therefore used. Rotary drilling is nearly always employed, and double or triple-tube core barrels are in common use for sampling. Although various insitu tests are conducted, the emphasis is on laboratory testing for the determination of engineering properties. In particular, shear strengths for residual soils are determined by high quality drained and undrained triaxial tests on saturated specimens.

INTRODUCTION

Hong Kong is a British-administered Territory at the mouth of the Pearl River on the southeast coast of China. Despite its small size, it is of international significance as the world's third largest port, and as a leading manufacturer and exporter. Its economic development over the past few decades has been phenomenal, and extensive civil engineering and building works have taken place in both the public and private sectors to support this.

The Territory has a land area of only 1050 sq. km with a population of nearly six million. It consists of Hong Kong Island and the Kowloon peninsula, which were ceded to Britain by China, together with the New Territories, which are on lease to Britain until 1997 (Figure 1). The New Territories comprise a piece of the Chinese mainland north of Kowloon and more than 200 small islands, the largest of which is Lantau.

The population is concentrated in a number of distinct geographical locations dictated to a great extent by the terrain. High concentrations of building development and population exist all along the north side of Hong Kong Island (Figure 2) and over the entire Kowloon peninsula, as well as in the new towns of Shatin, Tsuen Wan, Tuen Mun, Taipo and Fanling, which are currently under construction in the New Territories. Lantau, the largest island of the Territory, is largely undeveloped, but a few sizeable building developments have taken place there recently, and engineering feasibility studies have been completed for a new airport site on the north of the island. The other islands are mainly undeveloped and sparsely populated.

The terrain of Hong Kong is very hilly. The land rises from sea level to 550 m on Hong Kong Island in a distance of only 1.5 km. Most of the Kowloon peninsula has now been levelled, along with reclamation of adjacent sea areas, but isolated hills of up to 100 m still exist. Immediately behind Kowloon, hills rise to over 450 m. In the New Territories, very little low-lying land exists, and peaks of over 400 m are common. Natural slopes throughout the Territory are steep, typically with upper slopes greater than 35 degrees, midslopes of 25 to 30 degrees and footslopes of 15 degrees. Cut slopes formed for roads and site development works are commonly 40 to 80 degrees, and fill slopes are 30 to 35 degrees.

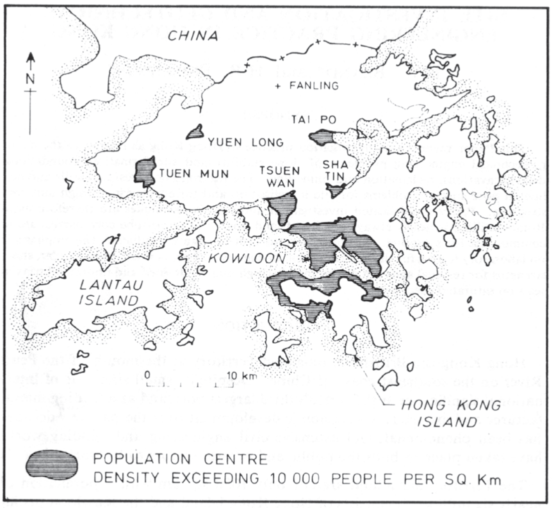


Figure 1. Map of Hong Kong

Hong Kong has experienced particularly spectacular economic and physical developments since the Second World War. The influx of immigrants from China caused the population to increase nine-fold between 1946 and 1984, and it has been necessary for the Territory to provide the facilities to accommodate the people and to sustain the Territory's economic growth. Large cut and fill site formation works have been taking place in the hilly terrain for many years

Figure 2. Aerial photograph of Hong Kong Island looking east showing concentration of building development along the coast (Note the new reclamation along the north shoreline, and the tip of the Kowloon peninsula at left)

to provide building land for residential, commercial and industrial developments, and these works are sometimes associated with the major reclamation schemes which are continually underway. Many residential and commercial blocks, up to more than 60 stories high, now dominate the shorelines of Hong Kong Island (Figure 3) and Kowloon. The huge public housing estates constructed by the Housing Department have mushroomed all over the Territory, together with the whole range of necessary educational, medical, recreational and public works facilities. New roads are constantly being built, often in very difficult terrain which requires considerable amounts of cut and fill.

About two-thirds of the Territory's small land area is considered undevelopable. The usable land is therefore an exceptionally valuable commodity. In the absence of flat land, highrise buildings and other structures are increasingly being built on the mid-slopes and upper slopes of natural hillsides, and this is generally difficult, nearly always very costly, and sometimes even hazardous. In these circumstances, very intensive use is made of all developable land.

The rainfall in Hong Kong averages 2225 mm annually, and more than 80% of this falls during the period May to September. Intensities can be high, with 50 mm per hour and 200 mm in 24 hours being not uncommon. Landslides in the steep terrain are therefore frequent.

Largely as a result of disastrous landslides in 1972 and 1976, the Government of Hong Kong established the Geotechnical Control Office (GCO) in 1977 to undertake a wide range of geotechnical engineering activities related to the safe and economic utilization and development of land, with particular emphasis on the stability of existing and future slopes associated with both buildings and engineering works.

As one of its long-term objectives, the GCO is

Figure 3. View along north coast of Hong Kong Island looking west (note new reclamation)

attempting to establish solutions for the many and varied slope stability problems and to develop more rational methods of slope design. In addition, it aims to develop better solutions to the full spectrum of geotechnical engineering problems and to improve engineering practice by providing technical documentation to disseminate these developments.

A general overview of the main geotechnical engineering problems in Hong Kong, and of the current design and construction practice, can be gained by reference to the papers by LUMB (1975) and BRAND (1982, 1984), which emphasize the slope stability and site formation problems of the Territory. The present site investigation practice has been summarised by BRAND & PHILLIPSON (1985), and BORRIE et al. (1984) have reviewed this practice in relation to the application of the British Code of Practice (BS 5930) to Hong Kong conditions. Sampling has been the subject of papers by BRENNER & PHILLIPSON (1979) and FORTH & PLATT-HIGGINS (1981). A recent paper by BRAND et al. (1983a) reviewed the insitu measurements and field instrumentation used in Hong Kong's residual soils and colluvium.

GEOLOGY

The geology of Hong Kong, which is summarised in Figure 4, has been described by RUXTON (1960) and ALLEN & STEPHENS (1971). The main rock types are granite and acid volcanic rocks, which together cover the major portion of the Territory and are by far the most important from an engineering point of view. The small amounts of sedimentary and metamorphic rocks are of much less importance, although some specific landslide problems have been associated with these. Granite predominates in those areas of the Territory where building development is densest.

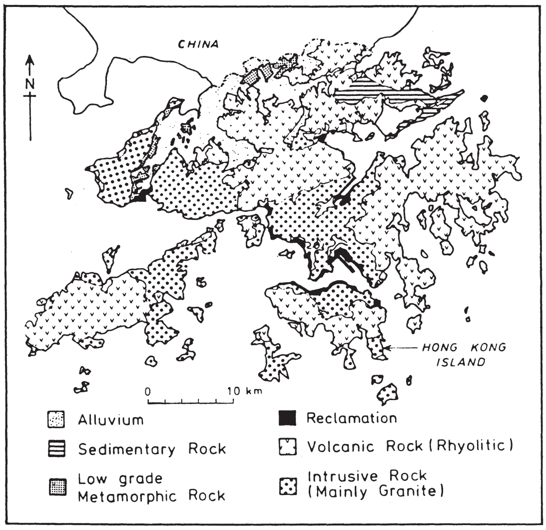
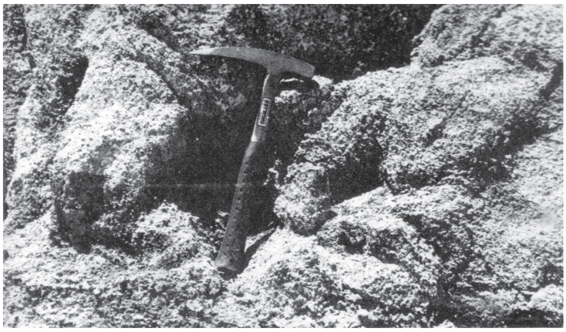


Figure 4. Geology of Hong Kong (Allen & Stephens, 1971)

(a) Fresh rock



(b) Residual granitic soil

(c) Residual granitic soil with corestones
Figure 5. Hong Kong granite in its many forms

The granite varies somewhat in colour and composition, but the fresh rock is fairly uniform in its engineering properties (Figure 5a). Of major significance for slope stability are the joint patterns and the extent of weathering. Joint spacings are typically 0.5 to 1 m, but they can be as wide as 3 m. In a few locations, sheeting joints occur almost parallel to the natural ground surface. The granite is extensively weathered almost everywhere, with depths of up to 60 m of silty-sandy residual soil (Figure 5b), often with large corestones in the matrix or exposed on the surface (Figure 5c). Below the residual soil mantle, a considerable depth of differentially decomposed material extends to great depth in a weathered granite profile. The weathering process in Hong Kong granite has been described by RUXTON & BERRY (1957).

The volcanic rocks consist mainly of coarse tuffs, fine tuffs and rhyolite but some ignimbrites and breccias also exist. These rocks are usually fine grained and have a blocky structure, with close joint spacings of generally less than about 0.25 m (Figure 6a). They are more resistant to weathering than the granite, the residual soil mantles being only up to 20 m thick (Figure 6b). A volcanic profile usually exhibits a steadily decreasing degree of decomposition with depth, the unweathered rock being reached at a much shallower depth than in a granite profile.

Steeply dipping dolerite dykes have been intruded in many places into the granite and volcanic rocks. These dykes, which vary in thickness between about

150 mm and 1.5 m, greatly complicate the engineering geology of many sites and are often a significant feature in landslides (HENCHER et al., 1984). Large granodiorite intrusions also exist in several places.

Of particular engineering geological significance in Hong Kong are the extensive bodies of colluvium which cover about 20% of the total land area. This accumulation of debris from old landslips and mass movements commonly carpets the lower slopes of most of the hills. It varies in composition from a boulder field to a fine slope-wash, but it most commonly consists of boulders, cobbles and gravel in a matrix of sand, silt and clay (Figure 7). The colluvium is up to 30 m thick in places. It is sometimes in a loose state, with a high permeability, and it frequently gives rise to perched water-table conditions. It is also prone to the formation of 'pipes' or 'tunnels' as a result of internal erosion (PIERSON, 1983; NASH & DALE, 1983; BRAND et al., 1984a), and these features can be of major significance to the hydrogeology of an area (LEACH & HERBERT, 1982).

(a) Fresh tuff

(b) Completely decomposed tuff
Figure 6. Hong Kong volcanic rock

Some engineering properties of the fresh and decomposed granite and volcanic rocks of Hong Kong have been reported by LUMB (1962a, 1962b, 1965, 1983). Additional information about the engineering geology of Hong Kong materials is available from three sets of Symposium Proceedings (HONG KONG JOINT GROUP, 1962; GEOLOGICAL SOCIETY OF HONG KONG, 1983, 1984).

(a) Typical volcanic colluvium

(b) Mixed granitic and volcanic boulder colluvium
Figure 7. Hong Kong colluvium

CLASSIFICATION OF WEATHERING PROFILES

Accurate and consistent descriptions of exposures and borehole samples are vital if a site investigation in a weathered profile is to be meaningful for engineering design. The heterogeneous nature of the materials involved presents particular difficulties in this respect.

The description and classification systems commonly used for soils are of little use with weathered rock profiles. Classification in terms of weathering 'zones' and weathering 'grades' is essential for engineering design, and there have been several major attempts to provide a satisfactory description and classification system for engineering purposes. DEERE & PATTON (1971) gave a valuable comparative summary of the classification systems available at that time. The GEOLOGICAL SOCIETY OF LONDON (1977a) made proposals for core logging which have been fairly closely followed by the ASSOCIATION OF ENGINEERING GEOLOGISTS (1978). The

Table 1. Weathering grade classification system recommended by the Geotechnical Control Office (1984)

Grade	Description	Typical Distinctive Characteristics
VI	Residual soil	Soil formed by weathering in place but with original texture of rock completely destroyed
V	Completely decomposed rock	Rock wholly decomposed but rock texture preserved No rebound from N Schmidt hammer Slakes readily in water Geological pick easily indents surface when pushed
IV	Highly decomposed rock	Rock weakened - large pieces can be broken by hand Positive N Schmidt rebound value up to 25 Does not slake readily in water Geological pick cannot be pushed into surface Hand penetrometer strength index > 250 kPa. Individual grains may be plucked from surface
III	Moderately decomposed rock	Completely discoloured Considerably weathered but possessing strength such that pieces 55 mm diameter cannot be broken by hand N Schmidt rebound value 25 to 45 Rock material not friable
II	Slightly decomposed rock	Discoloured along discontinuities Strength approaches that of fresh rock N Schmidt rebound value greater than 45 More than one blow of hammer to break specimen
I	Fresh rock	No visible signs of weathering; not discoloured

weathering classification system used in Britain has been embodied in the British Site Investigation Code of Practice (BRITISH STANDARDS INSTITUTION, 1981); this system is based largely on the report produced by the GEOLOGICAL SOCIETY OF LONDON (1977b), which is probably the most important publication on the subject of classification of weathered profiles.

The GEOTECHNICAL CONTROL OFFICE (1984) has adopted a weathering description and classification system which is based on the original work by MOYE (1955) and RUXTON & BERRY (1957), but which has several important additions proposed by HENCHER & MARTIN (1982). A profile in Hong Kong is logged according to the six grades given in Table 1 and the four zones described in Table 2. Figure 8 shows how a drillhole log relates to a weathering profile. Table 3 contains fuller information on the typical characteristics of the weathering zones and of colluvium and fill which commonly overlie the insitu materials. It is worthy of mention that the grades I to III materials are commonly referred to as ‘rock’, and the grades IV to VI as ‘soil’.

Colluvium often possesses many of the same general characteristics as residual soils, and the same care must be taken in dealing with this difficult material. Because it is commonly found as slope cover over weathered rock profiles, it is sometimes difficult to distinguish between colluvium and the insitu material, particularly if only drillhole samples are available for examination. BERRY (1957) has described some of the colluvial deposits of Hong Kong, and HUNTLEY & RANDALL (1981) have given some guidance on distinguishing these deposits from weathered insitu granite and volcanic rocks. There is no generally accepted system of description and engineering classification for colluvium in Hong Kong or elsewhere, although such a system is badly needed.

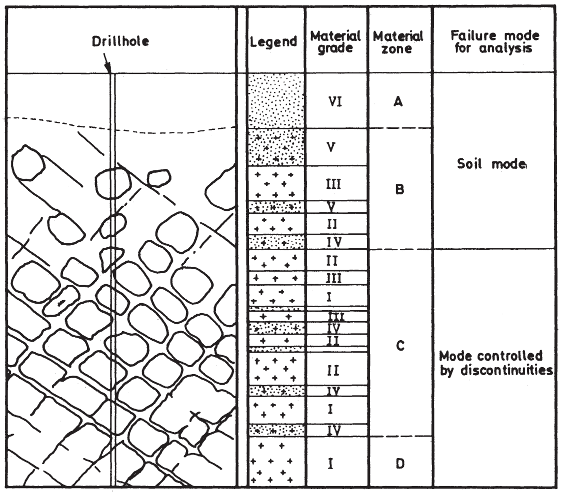
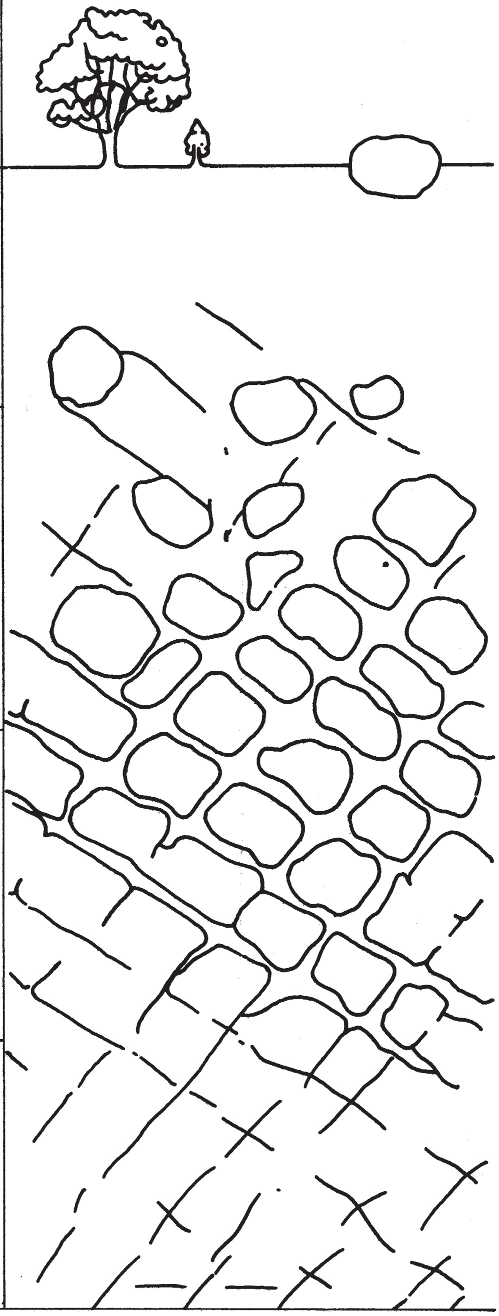


Figure 8. Relationship between Drillhole Log and Weathering Profile

Table 2. Weathering zone classification system recommended by the Geotechnical Control Office (1984)

Zone	Description of Weathering Zone
A	Structureless sand, silt and clay. May have boulder concentration at the surface.
B	Residual material with corestones. Rock percentage is less than 50%, and corestones are rounded and not interlocked.
C	Corestones with residual materials. Rock percentage is 50 to 90%, and corestones are rectangular and interlocked.
D	More than 90% rock. Minor residual material along major structural discontinuities which may be considerably iron stained.



GEOTECHNICAL ENGINEERING PROBLEMS IN HONG KONG

There is a wide spectrum of civil engineering and building projects in Hong Kong which rely heavily on site investigation data for design and execution. The specific geotechnical engineering problems associated with these projects include the stability of slopes

Table 3. Characteristics of the zones of material encountered in Hong Kong

Zone	Features of Exposures	Core Appearance	Sampling Method	Engineering Properties
Fill	Heterogeneous material which can comprise soil and/or rock of any grade. Rock fragments may show fresh fracture surfaces indicative of previous excavation and disturbance. Density variable, and the only structure visible may be that due to compaction in layers. May contain foreign material (e.g. tree stumps, building materials). Often easily eroded.	Structureless, heterogeneous material which can contain rock fragments of any grade and which may show fresh fracture surfaces. May contain foreign material.	Driven samplers. Loose fills not easily recovered and liable to severe disturbance by compaction during recovery. Triple-tube core barrel can be used.	Variable, depending on materials and degree of compaction. Loose fills liable to instability; very loose fills liable to form flow slides. Engineering properties determined by laboratory tests on samples recovered from loose fills may be optimistic because of disturbance.
Colluvium	Loosely packed, poorly sorted material of variable thickness which can often be great, and which may contain boulders. In an excavated face, frequently appears as a random distribution of decomposed boulders set in soil matrix. Boundaries of deposit often marked by sharp changes in topography.	Heterogeneous, structureless soil, often with boulders. All surfaces of boulders show signs of decomposition. No fresh rock surfaces or building debris.	Driven samplers or triple-tube core barrel. Double-tube barrel required if boulders are encountered. Continuous undisturbed samples obtained only from very careful drilling.	Can normally be excavated by hand, and is susceptible to surface erosion. Boulders, however, may complicate excavation and may require splitting. Soil slope stability methods should be used for analysis.
Zone A	Structureless layer of soil of variable thickness, but normally less than 2 m. Usually bright red or yellow, and shows none of the fabric of the rock from which it is derived.	Structureless soil showing none of the fabric of the parent rock. All grade VI material.	Driven samplers or triple-tube core barrel. Continuous undisturbed samples obtained only from very careful drilling.	Can normally be excavated by hand, and is susceptible to surface erosion.
Zone B	Zone of decomposed rock of very variable thickness, containing rounded and non-interlocking boulders which may be much harder than surrounding material. Original rock fabric preserved throughout. Grades IV or V material normally constitute more than 50% of the exposure.	Sections of grades IV or V material separated by sections of less decomposed material (boulders).	Driven samplers or triple-tube core barrel. Double-tube barrel required to sample boulders. Continuous undisturbed samples obtained only from very careful drilling.	Can normally be excavated by hand or machine, and is susceptible to surface erosion. Boulders, however, may complicate excavation and may require splitting. Stability of cuts normally depends on strength of dominant material but occasionally on geometry and nature of discontinuities. Soil slope stability methods should normally be used for analysis.
Zone C	Zone of decomposed rock of variable thickness containing rectangular blocks separated by thin seams of friable material. Original rock fabric preserved throughout. Grades IV or V material normally constitute less than 50% of the exposure.	Sections of grades I, II or III material separated by sections of grades IV or V material.	Double-tube core barrels, with triple-tube barrel in weak seams. Continuous undisturbed samples obtained only from very careful drilling.	Would normally be excavated by machine, supplemented by splitting of large boulders. Stability of cuts depends on geometry and strength of discontinuities. Rock slope stability methods should generally be used for analysis.
Zone D	Zone of rock which may have suffered a little decomposition. Friable material, if present, typically limited to narrow seams. Original rock fabric is preserved throughout. Grades I or II material normally constitute more than 50% of the exposure.	Sections of grades I or II material separated by sections of grades III, IV or V material.	Double-tube core barrel.	Normally requires blasting for excavation. Stability of cuts depends on geometry and strength of discontinuities. Rock slope stability methods should be used for analysis.

and site formation works, reclamation, tunnelling, deep excavation support, deep caisson construction, and driven pile installation. In many instances, well-designed site investigations have proved to be crucial, and there are several notable cases of serious construction problems, long project delays and large increases in costs because of inadequate initial site investigations.

Because of the heterogeneous nature of the residual and colluvial soils of Hong Kong, and because of the importance of rainfall effects, measurements of engineering properties and predictions of engineering performance are extremely difficult (BRAND, 1982). This applies particularly to the assessment of the stability of existing slopes and to the design of new ones.

Slope Stability

Geotechnical engineering practice in Hong Kong tends to be dominated by the slope stability problems brought about by the combination of the high intensity rainfall and the steep terrain. Several hundred failures may occur in a year, most of which are not of great consequence, but severe effects are felt from some of these in terms of casualties and damage. In fact, a significant landslide event, in which a large number of failures occur in one day causing considerable disruption and damage, can statistically be expected to take place in Hong Kong about once every two years (LUMB, 1975; BRAND, 1984).

The whole range of slope 'features' is prone to landslides in Hong Kong, including natural slopes, soil cut slopes, rock cut slopes, earth fill slopes, retaining walls and boulders. The majority of failures, and usually those with the most severe consequences, take place in man-made features or are triggered by man-made features, particularly cut slopes in soil (weathering grades IV to VI).

Cut slope failures in soil, or in mixed soil and rock now constitute by far the most common form of landslide. The volcanic rock profiles are more susceptible to failure than the granite profiles, and colluvium is frequently involved. The failures nearly always occur suddenly during intense rain without prior warning (BRAND et al., 1984), and most slip surfaces are shallow, the thickness of the failed zone usually being less than 3 m.

Cut slope failures in rock occur much less frequently than in soil slopes, but such joint-controlled failures do occur, and they can involve fairly large volumes of material (BRAND et al., 1983b).

The engineering methods applied to slopes in Hong Kong are governed largely by the Geotechnical Manual for Slopes (GEOTECHNICAL CONTROL OFFICE, 1984). Although this is intended to be a guidance document only, it has considerably more influence than might be supposed, because it forms the basis on which slope designs are checked for adequacy by the Geotechnical Control Office.

The Geotechnical Manual provides fairly broad guidance on slope-related matters, much of which has application to other spheres of geotechnical engineering in Hong Kong and elsewhere with similar conditions. Its twelve chapters are entitled: Geology of Hong Kong, Site Investigation, Laboratory Testing, Groundwater, Design of Slopes, Foundations on Slopes, Retaining Structures, Surface Drainage, Construction, Instrumentation, Maintenance, and Sources of Information.

The approach to the stability assessment of soil slopes recommended by the Geotechnical Manual, and almost universally used, is that of 'classical' limit equilibrium analysis by means of one of the proven methods for non-circular surfaces (e.g. JANBU, 1954, 1973), together with an appropriate factor of safety (BEATTIE & CHAU, 1976). For rock slopes, the methods suggested by HOEK & BRAY (1977) are generally used for plane, toppling and wedge failures (BRAND et al., 1983b).

The factors of safety recommended for the design of new slopes in Hong Kong are specified in terms of a ten year rainfall return period. As shown in Table 4, the recommended values depend on the risk to life and the economic risk, but they vary between only 1.0 and 1.4. To some extent, these low values are indicative of the fact that the classical methods of stability analysis tend to be conservative when applied to slopes in weathered profiles.

Table 4. Factors of safety for the design of cut slopes in Hong Kong (Geotechnical Control Office, 1984)

		RISK TO LIFE		
		High	Low	Negligible
ECONOMIC RISK	High	1.4	1.4	1.4
	Low	1.4	1.2	1.2
	Negligible	1.4	1.2	> 1.0

Note: these factors of safety are for a rainfall return period of ten years.

The main difficulties that exist in the application of classical methods of slope stability analysis to weathered profiles are as follows:

(1) Appropriate shear strengths cannot easily be assigned to the heterogeneous materials, and it is difficult to account for the effects of relict joints and boulders.
(2) The knowledge of the shear characteristics of unsaturated soils is scant, both in Hong Kong and elsewhere.
(3) Pore suction (negative pore water pressure) appears to play a significant part in soil slope stability, but its role cannot as yet be quantified.
(4) No adequate rational means exists for the

prediction of the pore pressure distribution along a failure surface under intense rainfall conditions.

Because of these difficulties, classical methods of analysis often yield factors of safety well below unity for slopes which have remained stable for many years. A major research and development effort is needed to resolve these issues, and some progress has already been made.

A programme of research work on the shear strength of saturated and unsaturated Hong Kong soils has been underway in the laboratories of the Geotechnical Control Office for a number of years, but still much more remains to be done before sound conclusions can be reached in this very difficult subject area, and only a few results have so far been published (RODIN et al., 1982). Some research work has also been undertaken in this direction by researchers in Canada (FREDLUND, 1981; HO & FREDLUND, 1982a, 1982b).

The prediction of critical groundwater conditions is considered to be by far the most problematical part of slope stability assessment in Hong Kong. Piezometers are commonly installed for this purpose (BRAND et al., 1983a), but measurements can rarely be taken over a sufficiently long period for adequate design information to be obtained. Numerical modelling techniques have been applied in a few cases (LEACH & HERBERT, 1982), but resort to simple direct correlation and extrapolation methods is more common (KOO & LUMB, 1981; ENDICOTT, 1982). Considerable effort has also been expended on the measurement of insitu soil suctions over long periods of time (CHIPP et al., 1982; SWEENEY, 1982; ANDERSON, 1984).

Foundations

All foundation types are employed in Hong Kong (LUMB, 1979), piled and caisson-supported rafts being the most common type for highrise buildings. Foundation design is intimately related to the method of construction and is often closely linked to the overall design and construction of site formation and slope stabilisation works (see below).

Site investigations for foundations are designed to determine the weathering profile, for the purposes of founding depths, and the groundwater conditions at the site. Settlement predictions are generally secondary because only small settlements usually occur, and these take place during construction of the building (LUMB, 1972).

Hand-dug caissons are constructed simply and economically in Hong Kong (FABER, 1972; LUMB, 1979), and these represent the most common foundation support for highrise buildings on weathered rock, although machine-dug caissons (bored piles) are being used increasingly. Diameters vary from 1 m to 3 m. It is often necessary for caissons to go to considerable depths before bedrock of adequate bearing capacity is reached, especially where they are founded in granite. Some examples of their use have been discussed by MACKEY & YAMASHITA (1967).

Driven piles are often difficult to install satisfactorily in residual soils and colluvium because of the presence of corestones and boulders. There is always danger that a pile will be founded on a boulder if the site investigation has not been sufficiently thorough to prove the depth to sound rock. For this reason, they are not much used except on reclaimed areas, where steel piles are the most common form.

Small diameter cast-in-place piles are not often employed in Hong Kong to take axial loads, driven piles usually being preferred where caissons are not used. Problems have been encountered with this type of pile where they have been used through soft marine sediments beneath fill on reclaimed areas. However, barrettes (rectangular cast-in-place piles formed by the slurry trench technique) are being increasingly used to support axial loads.

Deep Excavations and Retaining Structures

Because of the steep terrain, large excavations and retaining structures abound in Hong Kong. Deep basements to highrise buildings are also commonly employed to maximise land use, particularly in those areas where building height restrictions exist because of the proximity of the airport; the whole of the Kowloon peninsula comes into this category. Difficult temporary and permanent support problems are commonplace, particularly where excavations occur adjacent to existing structures or on steeply-sloping sites.

The execution and support of large excavations is frequently intricately related to considerations of foundation design and slope stability, and it is therefore often necessary for an integrated approach to be adopted to the overall site formation works (e.g. MICHAEL et al., 1981). In these circumstances, site investigations must extend well beyond the area of the building site itself, and care must be taken to account for the engineering geology of the whole area. For particularly large site formation works, some elements of the 'observational method' (PECK, 1969) are frequently employed, by which the designed works are modified as excavations reveal the true nature of the engineering geological conditions.

The form of the deep excavation support system employed for a particular project depends on the physical site conditions and the proximity of existing structures. Strutted sheet piling is most common on flat areas, which are largely reclamation (e.g. MORTON & TSUI, 1982), but diaphragm walls have become fairly popular in recent years for large excavations (OPENSHAW & MARCHINI, 1980). Cases of the use of diaphragm walls for large excavations have been described by McINTOSH et al. (1980), DAVIES & HENKEL (1980), and TAMARO (1981). Contiguous caissons or bored piles are often used, particularly on steeply sloping sites, to form temporary anchored retaining structures against which the permanent support structure is built (FLINTOFF & COWLAND, 1982); an example of this is shown in Figure 9. Less frequently, contiguous caissons or bored piles constitute permanent retaining walls. Anchored driven or bored king piles, infilled with precast concrete units as excavation proceeds, have also been used (e.g. BENJAMIN et al., 1978), as has construction by the 'top-down' method (e.g. BEATTIE & YANG, 1982).

Old retaining walls in Hong Kong were most commonly of masonry, but this is no longer used for anything other than very small retaining structures. Reinforced concrete is now the usual material. Anchored contiguous bored piles or caissons have been employed for some high walls (e.g. BEATTIE & MAK, 1982). Buttressed reinforced concrete cantilevered walls are fairly common, but temporary ground anchors are needed to support the excavated face while the wall is constructed; a 33 m high wall of this type has been described by VAIL & HOLMES (1982).

In the urban areas of Hong Kong, large deep excavations not infrequently cause damage to existing structures (e.g. DAVIES & HENKEL, 1980) for reasons of stress relief and groundwater lowering during excavation construction. Information on ground and building settlements associated with diaphragm wall construction has been published by COWLAND & THORLEY (1984). In addition, large basement structures and cutoff walls can adversely affect the groundwater regime on sloping sites, particularly in colluvial areas, by acting as impermeable boundaries, unless appropriate subsurface drainage measures are incorporated into the design.

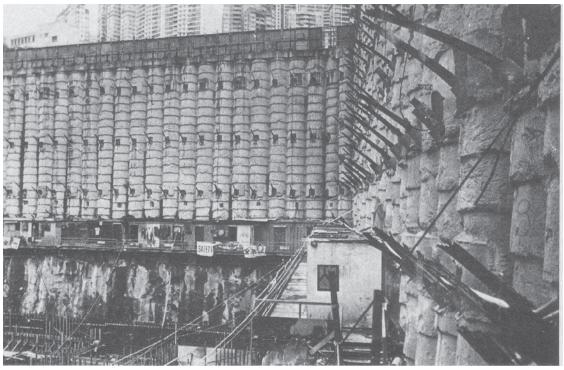


Figure 9. Example of a temporary anchored contiguous bored pile retaining wall in Hong Kong

Ground anchors (tie-backs) are a special problem in Hong Kong. Permanent anchors have been used extensively in recent years (Figure 10) without appreciation of the full implications of their unknown long-term integrity or of the importance of monitoring. After some years of looking closely at this problem,

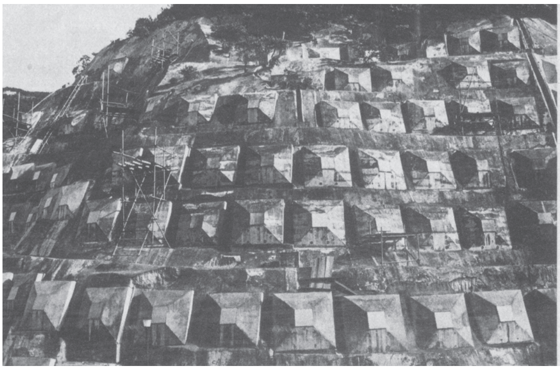


Figure 10. Example of the extensive use of permanent ground anchors in Hong Kong

the Geotechnical Control Office has recently produced its Model Specification for Prestressed Group Anchors (BRIAN-BOYS & HOWELLS, 1984a, 1984b), which should go a long way towards improving the standards of permanent installations. This document was written especially for Hong Kong conditions after consulting the British, German and Swiss codes of practice.

Reclamation

Reclamation has always been a feature of Hong Kong's development (TREGEAR & BERRY, 1959; LUMB, 1976; ELLIOTT, 1983), and this is likely to continue. Reclaimed areas are invariably used for the construction of highrise buildings (Figure 3) which require piled foundations. For this reason, 'soil' fill is usually used as reclamation material, but this is becoming increasingly difficult to locate within economic haul distances of the sea. It will probably become necessary for more rock fill to be used for reclamation in future, and satisfactory geotechnical solutions will be required for the foundations of highrise buildings on this material.

Reclamation is increasingly being carried out in areas where the large thickness of soft clay is such that it cannot economically be removed. In these areas, 'mud waves' can readily occur as the fill is placed, and unacceptably long times are needed for the clay to consolidate before the reclaimed land can be built on. Marine site investigations for these projects therefore concentrate on determining soft clay thicknesses and measuring the compression characteristics of this material. Vertical drains, usually of the plastic 'wick' type, are now sometimes used to accelerate the compression of the clay (e.g. FOOTT, 1982).

A typical reclamation project in Hong Kong has been described in the paper by HUNT et al. (1982).

Tunnelling

Some major tunnels have been driven in Hong Kong for roads, railways, and water supply purposes. Works are presently progressing on the large diameter water supply tunnels from China and on those for the Island

Line of the Mass Transit Railway.

Problems arise with tunnelling in Hong Kong conditions because of the uneven weathering of the rock, particularly in the granite, the often abrupt changes from 'hard' to 'soft' conditions, and the occasional unexpected rapid ingress of water. Damage to existing structures has also resulted from surface subsidence caused by stress relief, dewatering and the infrequent tunnel collapse.

Geotechnical feasibility studies, site investigations and construction methods for some major Hong Kong tunnelling projects have been described by CHAPPELL & TONGE (1975), HASWELL et al. (1980), McFEAT-SMITH (1982) and LINNEY (1983).

Some instances of apparently misleading or inadequate site investigation data have led to long delays and large contractual claims on some tunnel projects in Hong Kong, even where pilot tunnels have been driven as part of the investigations.

AVAILABILITY OF GEOTECHNICAL INFORMATION

There is a fairly extensive amount of published literature on the geology and geotechnical engineering of Hong Kong, as evidenced by a recent comprehensive bibliography (BRAND, 1985). The general geography text book by CHIU & SO (1983) provides excellent background reading, and the papers by LUMB (1975, 1983) and BRAND (1982, 1984) give good impressions of the engineering geological conditions, with particular emphasis on landslide problems.

Because of the Territory's small area, the map coverage of Hong Kong is good. For the more developed part of the Territory, 1: 1 000 scale plans are available, and the remainder is covered by several map series ranging in scale from 1: 1 200 to 1:20 000. The 1: 1 000 map coverage will eventually extend to the whole Territory.

Aerial photographic coverage of Hong Kong is excellent. Photographs have been taken since 1924, and annual photographic flights have been made since 1950. Complete coverage is available at scales of 1:8 000 and 1:20 000. It is now commonplace for aerial photographs to be taken for specific engineering purposes, and these are produced at scales ranging from 1:2 500 to 1:10 000. Oblique photographs are also taken. Only very occasional use is presently made of colour and infra-red photography, but this is likely to increase in future years.

Maps and aerial photographs are available for purchase by the public from the Lands Department of the Hong Kong Government, who also provide a fast enlargement service for aerial photographs.

A geological map of Hong Kong at a scale of 1: 50 000 is available. This was produced by ALLEN & STEPHENS (1971) and was accompanied by a geological survey report. The Geotechnical Control Office has recently started work on revising and expanding the scope of this survey, which will result in series of bedrock and superficial geological maps at a scale of 1: 20 000, accompanied by geological memoirs. The first of these will be available in 1985, and the whole series is planned to be completed by 1990.

Site investigation information from several thousand government and private sector projects has been assembled as part of the GCO Geotechnical Information Unit which is open to the public. Unfortunately, there is no statutory requirement for site investigation records to be forwarded to the GIU, and the information is therefore incomplete. A simple map grid reference system is used to retrieve information relevant to an area of interest, but this system is now being computerized. Other information, such as landslip records, old survey plans and tunnel records, is also included, and a system for the retrieval of groundwater data is now being developed.

The Geotechnical Control Office has for several years placed considerable emphasis on its Geotechnical Area Studies Programme (GASP) to provide systematic geotechnical input for land use management and development planning purposes. This programme and some aspects of the system of terrain evaluation employed have been described in several publications (BRAND et al., 1982a, 1982b; BURNETT & STYLES, 1982; STYLES et al., 1982).

Geotechnical Area Studies are carried out as either Regional Studies, at a scale of 1:20 000, or District Studies, at a scale of 1:2 500. Both series are based on aerial photograph interpretation, site reconnaissance and all existing geotechnical information. The results of each Study are embodied in a comprehensive report. This is accompanied by a set of transparent overlay maps, which typically comprises a terrain classification map, engineering data sheet, vegetation map, surface hydrology map, engineering geology map and geotechnical land use map (GLUM). The GLUM synthesises the findings of the study by classifying the terrain into four classes in terms of its geotechnical limitations to development (Table 5). Although these reports are at present only for use within the government, it is anticipated that they will become generally available in the near future.

ORGANISATION AND ADMINISTRATION OF SITE INVESTIGATION

General

The value of site investigation work carried out in Hong Kong is currently approximately US$10 million per year (1983 figure), of which about US$6 million is for government projects.

Site investigations for government projects are awarded on the basis of competitive tenders

Table 5. Geotechnical land use map (GLUM) classification system used in GASP (Brand et al., 1982 a, 1982 b)

Characteristics of GLUM Classes	Class I	Class 11	Class III	Class IV
Geotechnical Limitations	Low	Moderate	High	Extreme
Suitability for Development	High	Moderate	Low	Probably Unsuitable
Engineering Costs for Development	Low	Normal	High	Very High
Intensity of Site Investigation Required	Normal	Normal	Intensive	Very Intensive
Typical Terrain Characteristics (Some, but not necessarily all, of the stated characteristics will occur in the respective Class)	Insitu terrain with gentle slopes (0-15°), without severe erosion or instability. Cut platforms in insitu terrain.	Insitu terrain with slopes between 15 & 30° without severe erosion or instability. Insitu terrain of gentle slopes associated with drainage, but with no instability. Colluvial terrain with gentle slopes (0-15°), without severe erosion or instability.	Insitu terrain with slopes between 30 & 60° without severe erosion or instability. Insitu terrain less than 15°, with history of landslips. Colluvial terrain less than 15°, with evidence of instability. High to moderate fill slopes.	Very steep insitu slopes (>60°) and cliffs. Steep to very steep insitu and colluvial slopes, with history of instability. Colluvial terrain with gentle slopes, but associated with instability and drainage.
Note : This classification system is intended as a guide to planners and is not to be used for a detailed geotechnical appraisal of individual sites.				

by contractors on two approved 'Lists', which are under the technical control of the GCO. At present (June 1984), there are 16 contractors on the Lists, representing about two-thirds of all drilling contractors in Hong Kong. Seven of the contractors are on the List of those permitted to tender for contracts that exceed US$125 000 in value.

The site investigation for a private sector project is generally awarded on the basis of competitive tenders from a limited number of 'invited' contractors.

There is a constant turnover of companies in the site investigation industry. During the last five years, five contractors on the government Lists have ceased their site investigation operations, whereas eight new contractors have started business in Hong Kong. Only one contractor on the Lists is an independent site investigation company; the remainder are associated with contractors for geotechnical processes or civil engineering works.

Standards

Hong Kong does not have a long tradition of high standards of site investigation. Over the past five years, however, there has been an increasing awareness of the need for more extensive and better quality investigations, and this has led to a significant improvement in specifications and to a general rise in standards. The rate of improvement has not been as rapid as it might have been, because of the reluctance of private developers in many cases to spend more than the minimal amounts of money on investigations, and because of the unsatisfactory levels of supervision which have persisted. Very few site investigations have full-time supervision from the organisation responsible for the project design. Whereas a large number of government investigations have part-time supervision, usually in the form of daily visits, the majority of the investigations carried out in the private sector receive little or no supervision. The contractor's in-house supervision is quite often at a similarly low level.

The basic reference standards for site investigation practice in Hong Kong are:

(1) BS 5930: Code of Practice for Site Investigation (BRITISH STANDARDS INSTITUTION, 1981).
(2) BS 1377: Methods of Testing Soils for Civil Engineering Purposes (BRITISH STANDARDS INSTITUTION, 1975).
(3) Geotechnical Manual for Slopes (GEOTECHNICAL CONTROL OFFICE, 1984). Specifications for government site investigations

are either written or vetted by the Geotechnical Control Office. These are also becoming increasingly used as models for private sector site investigation documents.

The GCO is currently preparing a guide to good site investigation practice to complement BS 5930. This will be made available to the public when it is published at the end of 1984.

Planning

The quality of planning for site investigations varies between wide limits. For a building project on a straightforward site, it is not uncommon for a standard grid of drillholes to be ordered and carried out, regrettably without the project architect or engineer ever having visited the site; the developer even often initiates the investigation before appointing his architect or engineer.

At the other extreme, before commencement of a site investigation for a slope stability project, the GCO and other reputable organizations carry out detailed site reconnaissance and survey work, together with desk-top studies of aerial photographs, old and current maps and previous site investigation reports in the area. Once field work is in progress, drillhole locations and sampling and testing requirements are often changed as a result of the conditions revealed in the initial holes. In such cases, flexibility is incorporated into the planning and programming.

Personnel

Until very recently, few site investigation contractors had professionally qualified civil engineers, geotechnical engineers or geologists on their staff. The traditional role of the drilling contractor had not required such personnel. This situation has improved significantly in the last two years, and most contractors now employ an increasing number of professionals. Most government site investigation contractors have always been required to have a qualified site engineer to be responsible for the technical quality of both field and laboratory work.

There is a tendency in the industry for there to be a rapid turnover of non-professional staff. Because of the small area of Hong Kong, drillers can change company without domestic inconvenience, and this mobility has had a somewhat disruptive effect on efforts to improve standards. Another personnel problem is the high illiteracy rate amongst drillers, which hinders the productivity of satisfactory daily drilling records.

No official registration of professional geotechnical engineers exists. In government, however, consulting commissions for projects which entail a significant geotechnical content are only awarded to those organizations which are known to have adequate geotechnical professional resources. In the private sector, where all project designs must be submitted to government for approval, geotechnical submissions are only acceptable if prepared by legally designated 'Authorized Persons'. However, these are not necessarily geotechnically qualified.

Major discrepancies often exist in Hong Kong between sample descriptions provided by the drilling contractor, on the basis of small disturbed samples, and those prepared by the testing laboratory. The contractors' lack of experienced personnel to describe samples has been largely responsible for this problem, which is overcome by some consultants using their own geologists or engineers to describe all samples and to prepare drillhole logs.

Laboratory Facilities

There is a heavy demand for laboratory testing in Hong Kong, especially for sophisticated triaxial testing. Traditionally, and even now to a large extent, drilling contractors have limited their operations to field work, laboratory testing being carried out by separate companies. There are eight civil engineering contractors with laboratories on the government 'Lists' of soil and rock testing laboratories, of which six are independent of drilling contractors. These, plus several other independent laboratories, will probably continue to carry out most of the soil testing for the private sector. Four consulting engineering firms run their own testing facilities for use largely with their own projects.

The general quality and reliability of data obtained from laboratory tests carried out in independent laboratories are sometimes suspect. Overall standards are very often not as high as in most developed countries, and careful client supervision is usually necessary if high quality results are to be achieved. The situation in this respect, however, is improving rapidly.

The most comprehensive laboratory testing facilities, both in terms of size and sophistication, are those maintained by the Public Works Laboratories operated by the Geotechnical Control Office as a service to government departments. They have a staff of over 100 and are equipped for the full range of construction materials testing, including soils, rocks, aggregates, concrete and reinforcing steel.

DRILLING METHODS

The most common site investigation drilling method used in Hong Kong for 'soft' ground (grades IV to VI) is rotary-wash boring; rotary drilling is used in rock (grades I to III). Cable-percussion techniques are rarely used because of the difficulties of advancing holes through boulders in residual soils and colluvium.

The method of rotary-wash boring nearly always used to advance holes in 'soft' ground is to surge and drill casing down with water flush. In urban areas, the drilling water is usually obtained from fire hydrants. When rock is encountered, sampling is carried out by means of double-tube core barrels, usually until 5 m of fresh rock have been drilled.

Casing is always employed in Hong Kong for drilling in residual soils and colluvium. For routine drilling, N-size casing (OD 89 mm, ID 76 mm) is used, which enables Standard Penetration Tests with 'liner' samples or 38 mm diameter driven samples to be taken. When triple-tube core barrels or larger driven samples are to be obtained, either P-size casing (OD 140 mm, ID 127 mm) or H-size casing (OD 114 mm, ID 102 mm) is used. Downhole depths are usually measured by means of a weighted tape.

For economic reasons, tungsten carbide bits are usually used for residual soils and highly decomposed rock (grades IV & V). The use of diamond bits (MIRTL, 1977, 1979) is restricted to drilling through boulders and into bedrock (grades I to III).

Approximately 200 drilling rigs are available for site investigation work in Hong Kong. These are mostly light to medium weight machines of the skid-mounted type which are capable of delivering approximately 18 to 40 HP (13 to 30 kW); a typical rig is shown in Figure 11. Site investigation plant and equipment is obtained from many countries, the main suppliers being Britain, Australia, Japan, USA and France.

More than 500 m of exploratory hole are drilled in Hong Kong each day. The average hole depth is about 18 m but depths vary widely. Approximate average progress rates and all-in costs for the different investigation methods used are shown in Table 6.

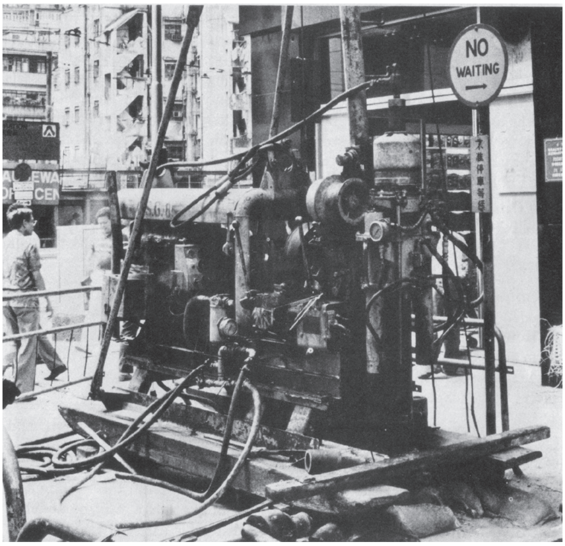


Figure 11. Common type of drillrig used in Hong Kong

Table 6. Approximate progress rates and all-in costs for site investigations

Site Investigation Technique	Speed, metres/day	Cost, US$/ metre
Basic wash-boring/drilling (N-size)	8-12	40
Triple-tube drilling (P-size)	4-8	100
High quality triple-tube drilling (air-foam, S-size)	4-8	200
Hand probing (GCO Probe)	30-40	5
Shallow trial pit (1.5 m x 1.5 m)	$\frac{1}{2}$-1$\frac{1}{2}$	100
Hand-dug caisson (1.8 m diameter)	$\frac{1}{2}$-1	600

Horizontal holes up to 220 m deep have been drilled in sound rock as pilot holes for tunnel construction. The drilling of horizontal holes in soils is much more difficult, but these are commonly drilled in Hong Kong to depths of up to 50 m for the installation of ground anchors. A few holes of up to 95 m long in residual soil and colluvium below the water-table have recently been drilled by the Geotechnical Control Office for the installation of horizontal subsurface drains, but great difficulties were experienced with hole collapse and drain insertion. Efforts are continuing to perfect the techniques of horizontal drilling and drain installation because of the wide potential application of horizontal drains as a soil slope stabilisation measure in Hong Kong.

Problems of access for drilling rigs are worth special mention, particularly since these sometimes represent the major cost element of an investigation in Hong Kong. On steeply sloping sites, timber scaffolding is widely used to form access roads and drilling platforms, an example of which is shown in Figure 12. For relatively remote sites, rigs are sometimes transported in pieces by helicopter where this is justified on economic grounds.

Much effort has been made recently to improve drilling methods and techniques for high quality sampling, including the Mid-levels drilling trial described below. Consequently, 'method' specification clauses are now used where high quality sampling is required; these detail the staffing and equipment requirements, and the drilling techniques that must be adhered to. Because of high costs, such high quality drilling is used only occasionally for government and private projects. Seven contractors on the government Lists are considered capable of carrying out such work.

Figure 12. Bamboo scaffolding used to support drillrigs on Hong Kong slopes

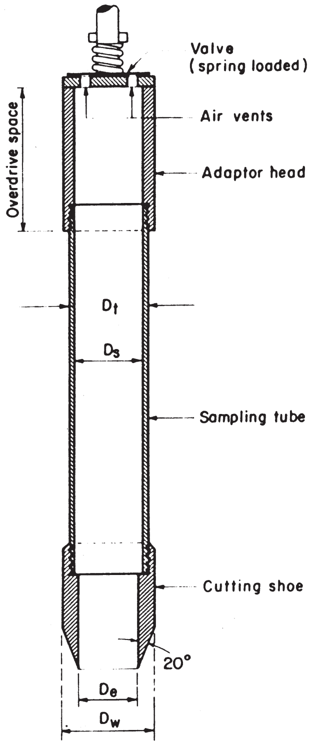


Figure 13. Open-drive sampler commonly used in Hong Kong

SAMPLING METHODS

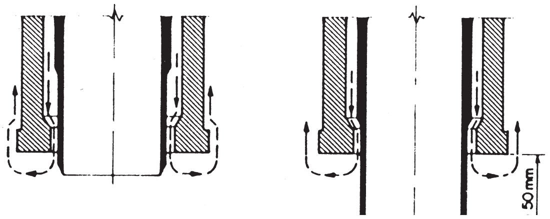
Various sampling methods are in use in Hong Kong which range from the use of basic drive samplers to sophisticated triple-tube core barrels (BRENNER & PHILLIPSON, 1979; PHILLIPSON & BRAND, 1985).

For private sector investigations, open drive-samplers that produce cores of 38, 76 or 102 mm diameter are unfortunately still widely used for obtaining 'undisturbed' soil samples from drillholes (Figure 13). These samples are generally unsatisfactory, because the high area ratios result in large sample compressions, and there is also the tendency for cutting shoes to be deformed on encountering gravel within the residual soils.

Double-tube ball-bearing swivel type core barrels are often used for drilling through boulders and into fresh and moderately decomposed rock (i.e. grades I to III) to produce cores of 40 to 92 mm diameter, but triple-tube core barrels are now in common use for good quality sampling in soil and rock. These barrels consist of a liner (innermost tube), an inner (holding) tube and an outer tube. The outer tube rotates to perform the coring while the inner tube and liner remain stationary. The sample is extracted from the core barrel in its liner, which provides good protection for the sample during extraction and subsequent transportation to the laboratory.

Two basic types of triple-tube core barrel are available. Non-retractable barrels are used for taking high quality cores in rock (grades I to III), while retractable barrels are used for coring the more friable materials (grades IV to VI). Retractable barrels have an inner tube with a cutting shoe which projects ahead of the drillbit when 'soft' material is being cored (Figure 14) so as to protect the sample from the drilling fluid. The inner tube retracts against a spring when hard material is encountered. Retractable barrels are therefore particularly useful when coring materials that vary appreciably in strength throughout the drillhole.

The triple-tube core barrel in most common use for sampling soils in Hong Kong is the Mazier sampler (MAZIER, 1974), which was introduced into the



(a) (b)

Figure 14. Principle of the retractable core barrel for sampling in: (a) rock, and (b) soils

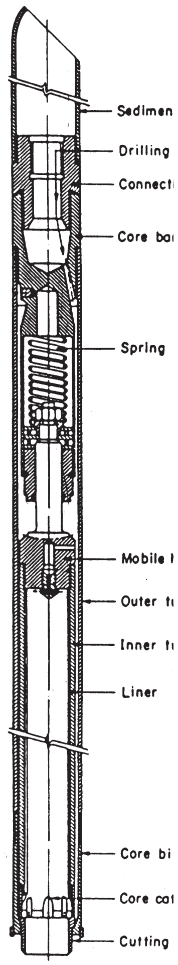


Figure 15. Details of the mazier triple-tube core barrel (Mazier, 1974)

Territory in 1974 (BEATTIE & CHAU, 1976) and which appears now to be in fairly widespread use in Europe (SALAS, 1977). Details of this retractable barrel are given in Figure 15. It produces a 73 mm diameter core up to 1 m long. The area ratio of the cutting shoe is 14%. PVC liners are favoured, but brass ones can also be used. The Mazier sampler cannot core rock, and it is most commonly used in conjunction with the double tube Craelius T2-101 core barrel for rock sampling.

The Triefus HMLC triple-tube barrel, which produces a 63 mm diameter core, is also frequently used, both as a retractor barrel for soils and a non-retractor barrel for rocks. Triefus triple-tube barrels which produce 102 mm diameter cores have also been used successfully in conjunction with air-foam as the flushing medium (see below) to obtain excellent core quality in residual soil and colluvium, the latter being the most difficult of the local soil types to sample. The use of this method is likely to continue on a limited scale.

Disturbed soil samples are commonly used for examination during drilling, for the purposes of preliminary drillhole logging, and for identification tests in the laboratory. 'Liner' samples are usually obtained in conjunction with Standard Penetration Tests, and disturbed samples are taken from cutting shoes of both open drive-samplers and triple-tube barrels. These are kept in air-tight jars or plastic containers. Wash samples are also commonly used for this purpose, but these can be very misleading because of the loss of the fines.

In addition to full visual descriptions, rock cores obtained from good quality site investigations in Hong Kong are invariably described in terms of Total Core Recovery, Rock Quality Designation, and Fracture Index (LUMB, 1983); a good quality drillhole log is shown in Figure 16. Full page colour photographs are also taken of core boxes. As well as providing valuable information for engineering assessment, these full core records are necessary in Hong Kong because the high cost of land and the heavy demand for premises results in soil and rock samples not usually being stored for long periods. For government site investigations, for example, all samples are disposed of as a matter of course after a period of three months unless instructions are given to the contrary.

TRIAL PITS

In conjunction with drillholes, trial pits are now commonly used on Hong Kong's soil slopes to enable much fuller engineering geological information to be obtained. They provide a means of partially 'calibrating' drillhole logs, of examining such important features as relict joints, and sometimes of enabling boundaries to be determined with certainty between fill, colluvium and residual soil. Because the majority of slope failures occur on shallow slip surfaces, a trial pit of 3 to 5 m deep is usually sufficient for a full-depth inspection of the likely failure zone in any existing slope.

Trial pits are usually 1.5 to 2.0 m square. Detailed logging of all four sides has been introduced by the GCO (Figure 17). This is by no means standard practice, an 'average' (or one-sided) log being commonly produced.

Insitu soil density testing is frequently carried out in trial pits, and densities are often related to standard compaction tests. To obtain undisturbed samples, tubes are driven or jacked into the sides or base of the pit. Occasionally, for research-quality laboratory investigations, 300 mm cube block samples of residual soil and colluvium are taken in trial pits by trimming and boxing insitu. Unlike drillhole samples, block samples offer little possibility of mechanical disturbance, and they do not suffer changes in moisture content due to drilling fluid. They also enable more representative strength tests to be conducted to account for such features as relict joints (e.g. KOO, 1982).

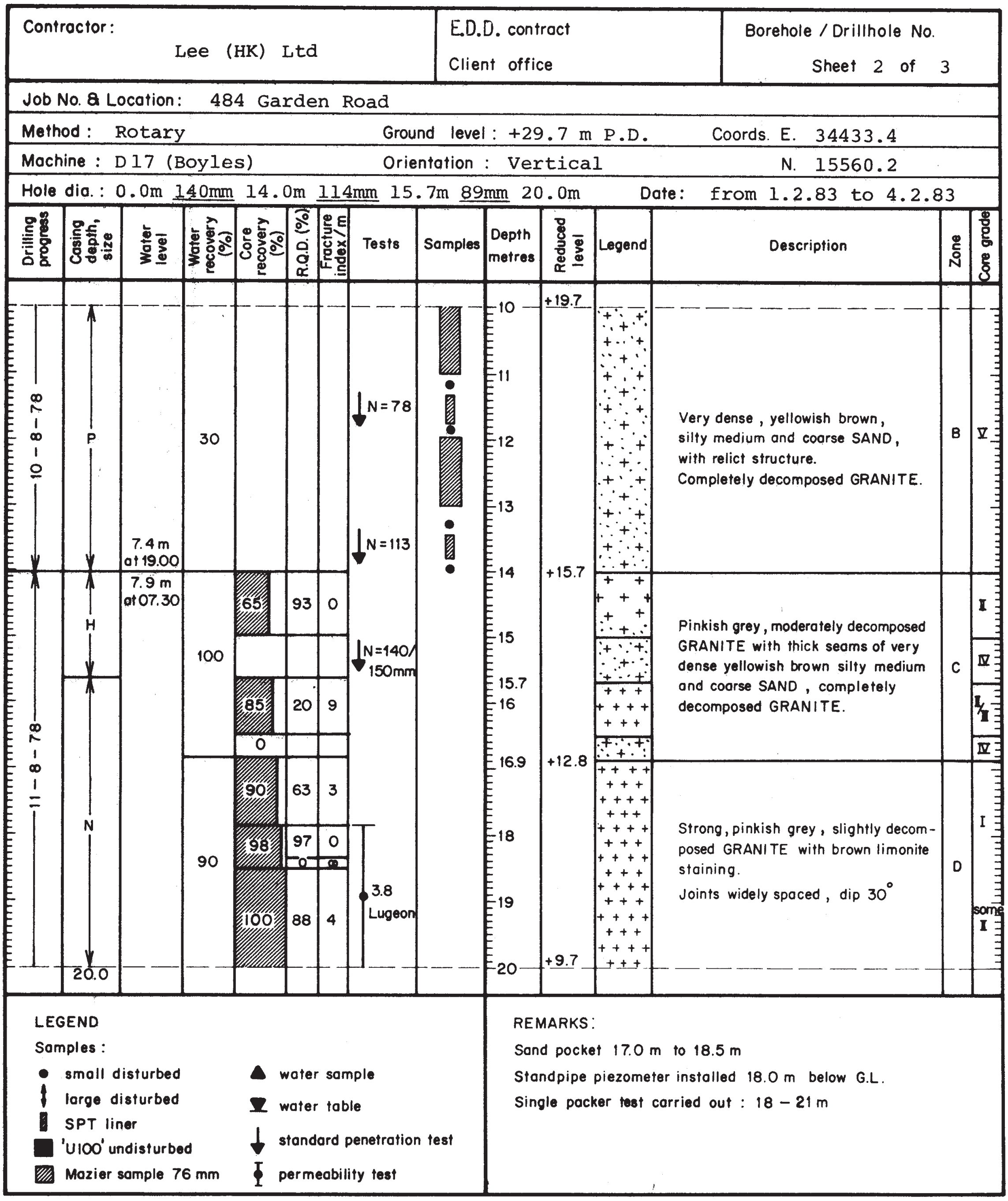


Figure 16. Typical good quality drillhole log in Hong Kong

Many cut slopes in Hong Kong are protected against surface erosion by a 'plaster' composed of cement-lime stabilised soil, known as 'chunam'. It is common practice in site investigations which involve slopes to remove strips of chunam or other protective material, and to log the exposures in a manner similar to that used for trial pits.

Hand-dug caissons, typically 1.8 m diameter, are occasionally adapted for the sinking of deep trial pits up to 30 m deep where groundwater presents no problems (e.g. CHIPP et al., 1982). The expense involved, however, is only justified for major projects.

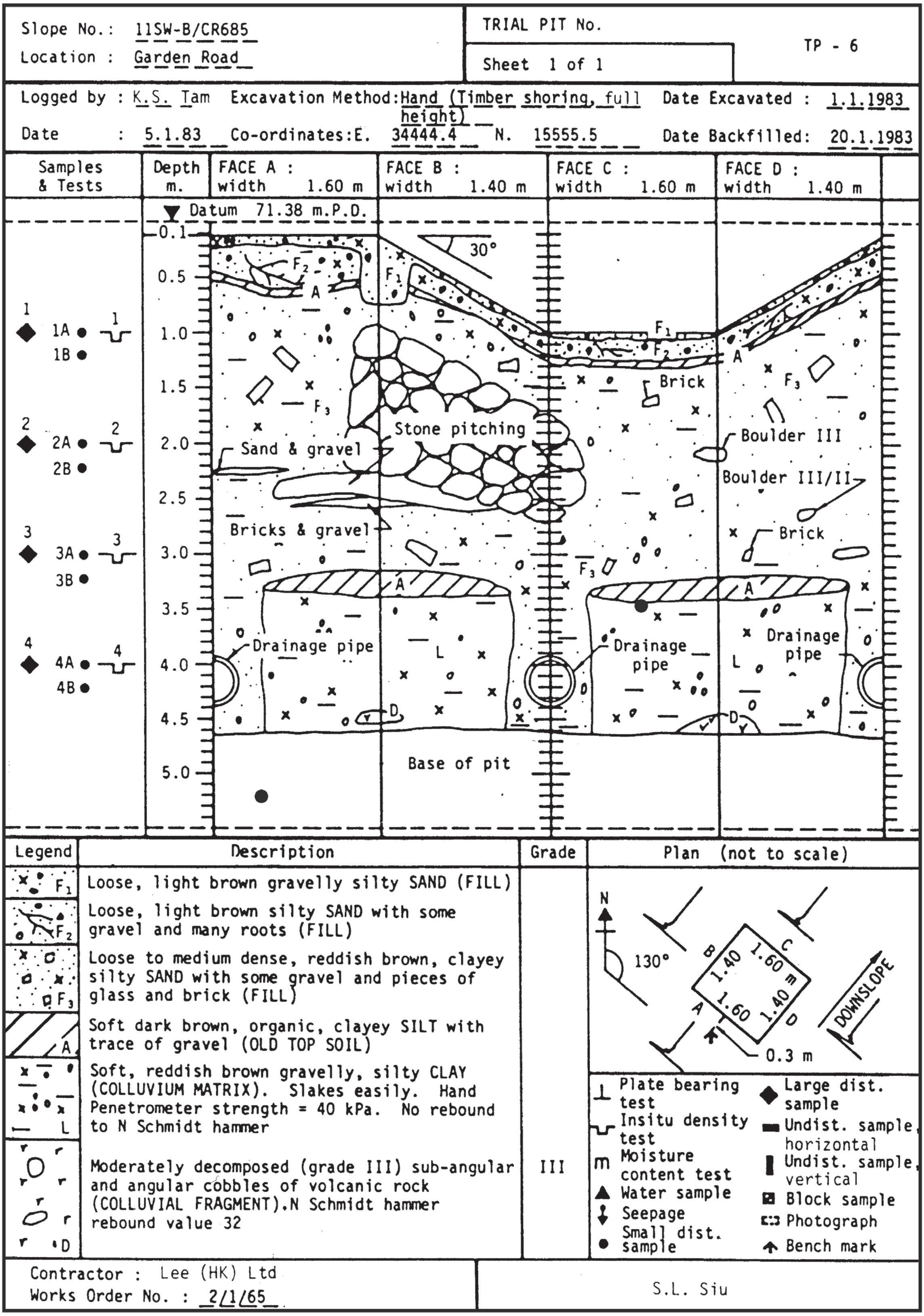


Figure 17. Four-sided trial pit log used in good Hong Kong practice

MID-LEVELS DRILLING TRIAL

An important drilling trial was carried out in the Mid-levels district of Hong Kong a few years ago (PHILLIPSON & CHIPP, 1981, 1982) to determine the best sampling method for obtaining the highest quality samples of residual soil and colluvium for the purposes of detailed geological identification and research standard shear strength measurements. This was part of a major geotechnical study of the Mid-levels district (GEOTECHNICAL CONTROL OFFICE, 1982; RODIN et al., 1982). Holes were drilled at a location where colluvium overlay decomposed volcanic tuff using the six different combinations of core barrels and flushing media shown in Table 7.

The *Triefus HMLC* triple-tube core barrel can be used with or without a retractable cutting shoe for coring both soil and rock. Because this had been used with water as the flushing medium during the early stages of the Mid-levels site investigations, it was considered to be appropriate as a 'standard' against which to compare the other sampling methods.

The *Longyear PQ wireline* is a non-retractable triple-tube barrel which incorporates a wireline mechanism for withdrawing the inner tube up through the drillrods without having to withdraw the outer barrel or rods from the hole. Wirelines have the major advantages of rapid hole advancement due to reduced 'turn-around' time between core runs, and maintenance of a fully cased hole at all times. However, it was found that bit blockages easily resulted unless a high rate of flow of the flushing fluid was maintained, and this resulted in poor core recovery (see below).

The *Mazier* triple-tube barrel for soil was used in conjunction with a double-tube *Craelius T2-101* barrel for rock, as being representative of good sampling practice in Hong Kong.

The *Triefus 4C-MLC* triple-tube barrel (Figure 18) is a larger version of the HMLC sampler, and it can be used with or without a retractable cutting shoe. The 102 mm diameter cores are suitable for testing in a standard laboratory triaxial cell or in a standard shear box, and they can readily be trimmed to smaller specimens.

Table 7. Samplers and flushing media used in the Mid-levels drilling trial (Philipson & Chipp, 1982)

Core Barrel	Core Diameter, mm	Flushing Medium
Triefus HMLC	63	Water
Triefus HMLC	63	Mud
Triefus HMLC	63	Air and air-foam
Mazier and Craelius T2-101	73 and 84	Water
PQ Wireline	83	Water
PQ Wireline	83	Mud
Triefus 4C-MLC	102	Air-foam

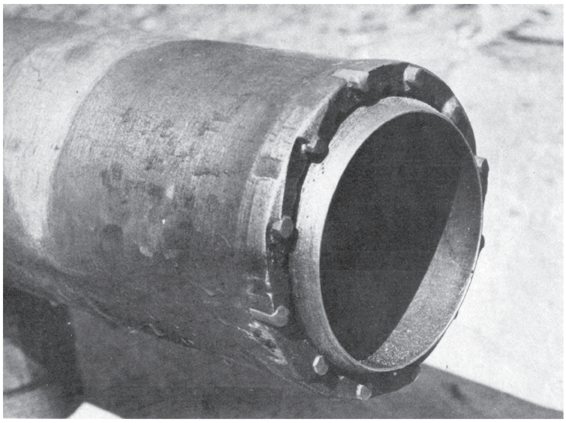


Figure 18. Triefus 4C-MLC triple-tube core barrel

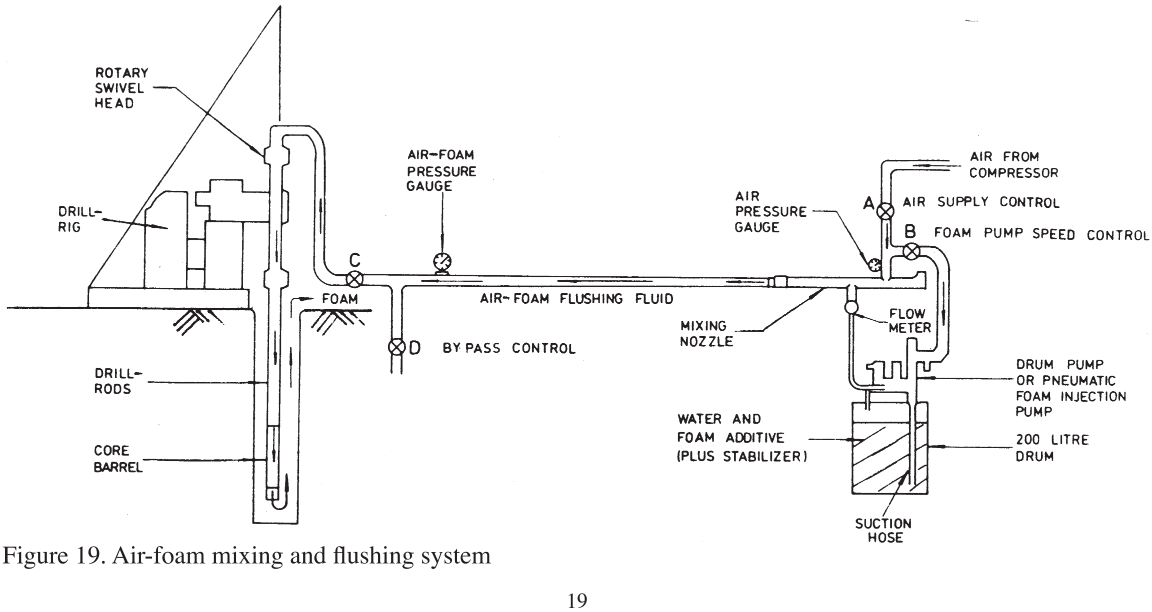


Figure 19. Air-foam mixing and flushing system

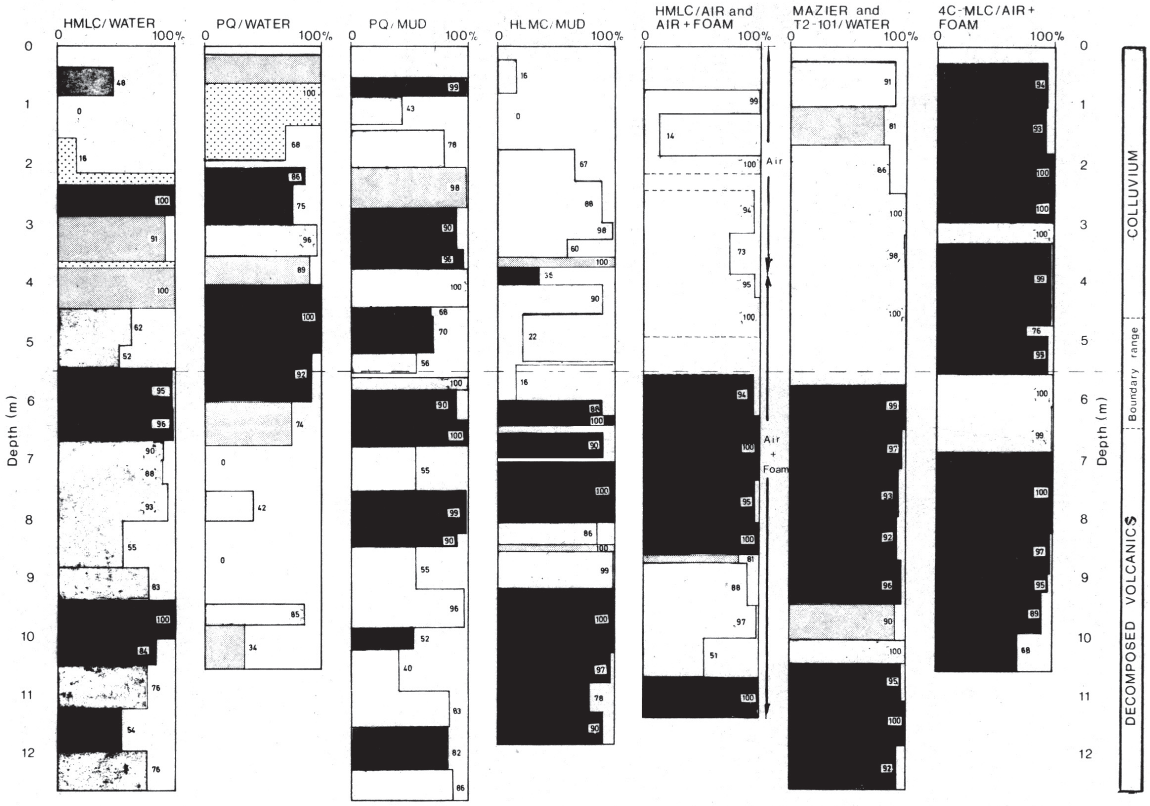


Figure 20. Results of the drilling trial in terms of core recovery and core quality (Note that a higher density of shading indicates better quality)

Water was used as the flushing medium with three of the samplers, and drilling mud produced by means of a biodegradable additive was also tried with two of these (Table 7). Air flush was used briefly with the HMLC barrel, but this was soon abandoned because the samples were badly disturbed by the high up-hole velocities needed to clear the cuttings (about 20 m/sec) and because of the high noise and dust levels.

Air-foam was used as a flushing medium for the first time in Hong Kong. The mixing and flushing system is illustrated in Figure 19. Foam additive is mixed with the water in the drum. Compressed air is used to operate the foam ejector pump on the top of the drum, which pumps the liquid foam mixture into the airstream through an ejector, at a rate controlled by valve B, to form air-foam which passes down the drillstring. This air-foam mixture is very viscous compared with water and requires only a low velocity (1 m/sec) to clear cuttings. The liquid part of the foam is consumed at a rate of about 2 to 4 litres/min, compared with the normal consumption of about 20 to 40 litres/min for drilling water.

The results of the drilling trial were assessed in terms of core recovery and core quality, both of which are represented in Figure 20 for each of the seven combinations of core barrel and flushing medium. Core quality is indicated by the intensity of shading. Black represents completely intact full-circumference core with no scour, and grey and dotted shading indicate decreasing core quality. Dotted shading represents non-intact core with loss of matrix material, whereas white represents no core recovery.

It can be clearly seen from Figure 14 that the best results were obtained using the 4C-MLC barrel with the air-foam flush; high quality core was obtained with a mean core recovery of over 95% . The use of drilling mud with the HMLC and PQ wireline appeared to result in only small improvements over the use of water, and the air flush obviously resulted in poor sample quality. Air-foam was consequently adopted in conjunction with the Triefus 4C-MLC barrel for sampling for the Mid-levels Study, and this has become the acceptable technique in Hong Kong where very high quality samples of residual soil and colluvium are required.

INSITU TESTS

Penetration Tests

The Standard Penetration Test is widely used in

Hong Kong for the assessment of subsoil profiles and for obtaining crude estimates of quantitative design parameters (e.g. WALKER et al., 1972). Trip hammers have been specified in government contracts for the last five years, but they had not been used at all in Hong Kong before that. Even now, they are not used for many private sector investigations. Liner samples are usually obtained in conjunction with the SPT, and these are found to be very useful in helping to interpret the results.

Because of the varying degrees of weathering of the parent rock, SPT values are often continued to much higher levels than in most other countries. This is illustrated in the SPT-density relationship shown in Table 8. However, this practice is now discouraged by the GEOTECHNICAL CONTROL OFFICE (1984) because it damages equipment and can lead to meaningless interpretations.

Table 8. SPT-Density relationship commonly used in Hong Kong

Description	'N' Value (number of blows)
Very loose	3
Loose	3-6
Medium dense	7-50
Dense	51-250
Very dense	>250

Heavy soundings are sometimes used for establishing founding levels for piles. Typically, a 125 kg weight dropped 760 mm is used to drive a 50 mm diameter cone.

A hand probe, known as the 'GCO Probe', is increasingly being used. This is essentially a larger version of the Mackintosh probe. It has a 10 kg hammer which is dropped 300 mm. The probe point is 25 mm diameter. Blow counts for each 100 mm penetration are recorded and plotted. The driving energy is such that probes have been carried out to 25 m in residual grade V decomposed granite. For the investigation of an existing slope, a large number of probes are initially made to obtain a general indication of the subsoil profile. This information is used to assist in the location of subsequent trial pits and drillholes. The probe is also used for assessing the degree of compaction of buried fill.

The Dutch cone test is not applicable to residual soils, and its use in Hong Kong is confined to the soft clays encountered in marine investigations (see below).

Pore Pressure Measurements

Accurate information on groundwater and its variations with rainfall is usually vital for the design and construction of slopes and site formation work in Hong Kong. Piezometers are commonly employed for this purpose. These are placed in completed drillholes, either at the hole bottom or at a level of subsoil change, sometimes with two piezometers in one hole. Although piezometer tips are usually 300 mm long, the surrounding sand filter is usually extended both above and below the tip to a depth of 1 to 2 m. This is to ensure interception of groundwater from preferential drainage paths such as joints or relict joints. The piezometers are provided with standpipes (usually 25 mm ID), and measurements are made by dipmeters. Halcrow 'buckets' (BRAND et al., 1983a) are sometimes installed in standpipes to record the highest transient water levels at times of heavy rain, and sophisticated automatic recording systems have also been used for some projects (POPE et al., 1982).

For site investigations where supervision levels are low, observation wells are often left in drillholes for groundwater measurements. These usually consist of PVC tubes (25 mm ID) perforated or slotted for their full length, surrounded by fine aggregate, and protected from surface infiltration by a concrete surround and surface box.

Because of the significance of suction forces (negative pore water pressures) to the stability of slopes in Hong Kong, agricultural 'jet fill' tensiometers with lengths from 0.5 to 3.0 m have been installed within the last few years on several sites for research and stability assessment purposes (e.g. CHIPP et al., 1982; ANDERSON, 1984). Twin-lead tensiometers with automatic recording have also been used (POPE et al., 1982, ANDERSON, 1984). The initial attempts to measure insitu suctions employed pyschrometers, but these were found to be unreliable for the measurement of low suctions, and they were subsequently abandoned.

In situ Strength Measurements

In general, very little testing is carried out insitu in Hong Kong for the determination of soil and rock strengths. For geotechnical design purposes, reliance is placed almost completely on laboratory tests. However, there are a few examples of direct and indirect measurements having been made. A shear box for the insitu testing of 300 x 300 mm soil or soft rock specimens has recently been used with some success by the GCO (BRAND et al., 1983c).

The pressuremeter has been used in drillholes on a limited number of projects in Hong Kong (e.g. CHIANG & HO, 1980) but, largely because of interpretation difficulties, its use is uncommon. Surprisingly, this is also true of the plate loading test, the use of which has been recorded on only a few projects (e.g. SWEENEY & HO, 1982).

Geophysical Methods

Geophysical methods are frequently used in Hong Kong in conjunction with widely spaced drillholes, for large marine investigations and for borrow area investigations on land (RIDLEY-THOMAS, 1982). Surface seismic refraction methods are used on land, with hammer techniques for shallow depths, and explosives where practical for greater depths (e.g. FORTH & PLATT-HIGGINS, 1981). Seismic reflection methods are used in conjunction with echo soundings for marine investigations, ultrasonic pulses being used as the energy source.

Because of the gradually changing weathering profile often encountered, the interpretation of geophysical data, even by experts, can be suspect unless calibrated against drillholes.

Other Insitu Methods

Permeability testing in drillholes is fairly frequently done. Constant-head and falling-head tests are carried out in partially-cased holes or with mechanical, hydraulic or pneumatic packers. Falling-head tests in piezometers are also sometimes conducted.

Because of the importance of joint orientation in rock stability analyses, more frequent use is now being made of the Triefus Borehole Impression Packer Device . This is used in uncased sections of H- or N-size drillholes to enable an orientated impression of discontinuities to be obtained.

Lutz electronic parameter recordings, used with top-drive rotary percussion drills, have also been employed, though rarely.

Pile loading tests and rock and ground anchor pulling tests are frequently carried out, the latter being a statutory requirement. Inclinometers are occasionally used to monitor horizontal movements of deep excavations and slopes, and some major projects have included lateral pressure measurements on retaining structures (e.g. VAIL & HOLMES, 1982). Groundwater surveys with tracers have been employed in a few instances.

California Bearing Ratio (CBR) tests are commonly employed as the basis of road pavement design. The

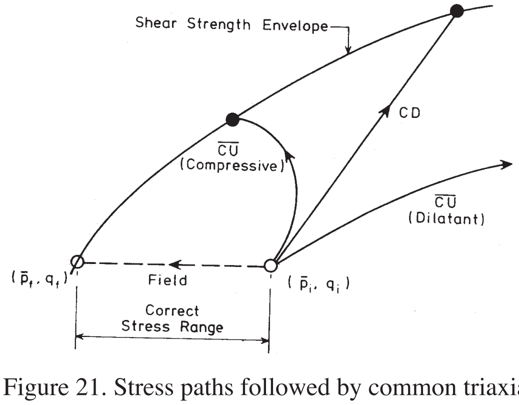


Figure 21. Stress paths followed by common triaxial tests in comparison with the stress path for a rain-induced slope failure (Brand, 1981)

compaction of embankments and other bodies of fill is controlled by insitu density measurements by means of the sand replacement or water replacement (Washington densometer) method.

Trial Embankments

Full-scale field trials are almost unknown in Hong Kong because they are generally inappropriate to the local conditions. Only two such proposals appear to have been made, both for trial embankments on marine clay, and only one of these has so far been adopted. As part of the engineering feasibility study for a proposed airport, to be sited on reclamation on the north of Lantau Island, a very large full-scale trial embankment was constructed in 1981-83 to provide design information (FOOTT, 1982). It is possible that future projects which involve construction over soft clay will also include trial embankments.

MARINE SITE INVESTIGATIONS

Since no part of Hong Kong is further than 10 km from the sea, there is inevitably a large amount of coastal development, such as reclamation schemes, harbours, dock facilities, coastal roads and bridges. These works produce a steady demand for marine site investigations, many of which are carried out in shallow waters less than 10 m deep. More than 5000 marine holes have been drilled in Hong Kong waters in the past thirty years, of which 1400 have been in the Victoria Harbour area. The soft marine clays encountered on the seabed (LUMB & HOLT, 1968; LUMB, 1977) are becoming increasingly significant for engineering projects, and more attention is now being paid to their distribution and engineering properties, especially their compression characteristics under reclamation loads.

The drilling rigs and equipment used for marine investigations are generally the same as those in use on land. For soft sediments, however, vane shear testing is often carried out, usually with the basic non-retracting vane, but occasionally using a vane borer of the *Geonor* type. Sampling of soft sediments is by means of driven thin-wall samplers or stationary piston samplers. The sample tubes are usually 75 mm ID, with an area ratio of 8%. Dutch cone tests are only occasionally employed, but their use is increasing.

There is a wide variation in the types of marine platform used for drillrigs depending on the requirements of the investigation and on the project location. For shallow waters, pontoons approximately 10 m long and 5 m wide, are used; these have the advantage that drilling can continue when a craft is beached at low tide. For deeper waters, pontoons or small boats are often relied upon but, because of boat motion, little more than SPT surveys can be achieved together with occasional crude rock drilling. Better results are obtained when the standard Hong Kong 'lighter' barge is employed; this is 30 m long and 10 m wide and, when ballasted, it provides a fairly stable drilling platform in sheltered water.

Large jack-up drilling platforms have been used for major investigations. The use of fixed drilling platforms, however, is normally restricted to shallow water work for vane testing and piston sampling.

Geophysical methods are in fairly common use for marine investigations in Hong Kong, particularly the seismic reflection methods for seabed profiling (RIDLEY-THOMAS, 1982).

LABORATORY TESTING

The full range of standard laboratory tests on soils is carried out in Hong Kong's testing laboratories, but the emphasis is on identification and strength tests. Consolidation and permeability tests are relatively rare because of the nature of the residual soils. The extensive use of analytical methods of slope stability analysis has led to a great deal of laboratory shear strength testing being carried out in the form of high quality triaxial tests (BEATTIE & CHAU, 1976), but the direct shear test (shear box) is now regaining popularity (GEOTECHNICAL CONTROL OFFICE, 1984).

Triaxial Tests

For slope stability problems, effective strength parameters are generally measured on saturated specimens by means of consolidated-undrained triaxial tests with pore pressure measurement (WONG, 1978, 1982; GEOTECHNICAL CONTROL OFFICE, 1984). Specimens are usually 73 mm diameter (from Mazier samplers) or 100 mm diameter (from Triefus 4C-MLC samplers or block samples), but some 37.5 mm diameter specimens are still sometimes employed. The use of full drillhole cores is favoured because of the extreme difficulties of trimming samples to produce good test specimens of smaller size.

The triaxial test procedures follow, in a general way, those recommended by BISHOP & HENKEL (1962), but more modern test equipment and instrument systems are usually employed. Back pressures of up to 400 kPa are used to obtain saturation ($\bar{B}$ = 0.97) prior to test. Compressed air systems are in most common use for providing cell pressure and back pressure, but a few mercury pot systems are still employed. Pore pressure measurement is always by electrical pressure transducers.

Multi-stage triaxial test are employed extensively (LUMB, 1964; WONG, 1978), because of their lower cost and because many engineers believe the results to be more useful than those from single-stage tests. There are often wide variations in samples of residual soil obtained from one location, and the results of strength tests can be difficult to interpret unless a large number of tests is carried out. Multi-stage tests eliminate this variability and enable a strength envelope to be obtained for the one material. This test is open to misuse, however, since erroneous results can be obtained if each stage of strain application is not terminated when the maximum principal stress ratio is achieved (LUMB, 1964; WONG, 1978; HO & FREDLUND, 1982).

As illustrated in Figure 21, the commonly used procedure for triaxial tests does not follow the correct stress path applicable to rain-induced slope failures, nor does it duplicate the field stress range (BRAND, 1981). Because of these objections, equipment has been developed in the GCO's laboratories whereby triaxial specimens subjected to a fixed deviator stress are brought to failure by increasing the pore pressure from an initially negative (suction) value. Similar equipment has also been developed elsewhere (HO & FREDLUND, 1982b). This test method is too complicated for routine use, but it is providing valuable research data.

Direct Shear Tests

The direct shear test offers a quicker means of measuring shear strengths which are regarded by some as being more applicable to slope stability analysis in Hong Kong than those determined under the unfavourable conditions imposed by back-saturation in the triaxial test.

The shear boxes in use in Hong Kong take 60 mm and 100 mm square specimens or, with adaptors, circular specimens. A specimen is soaked to achieve a high degree of saturation, before it is consolidated and sheared while immersed in water.

Shear box tests give strengths which are equal to or higher than those measured in the triaxial test. Higher strengths are usually obtained for materials which have a brittle behaviour during shear. The shear box has proved to be particularly valuable for investigating the effects of relict joints on shear strength (KOO, 1982) because specimen orientation can be readily varied.

For rock slope problems, which are joint controlled, direct shear equipment has been developed in Hong Kong to measure shear strengths on rough joints (HENCHER & RICHARDS, 1982; RICHARDS & COWLAND, 1982). This has enabled more reliable (i.e. higher) strength data to be obtained from tests on rock cores, which has resulted in more realistic rock slope stability assessments being made than were previously possible.

Consolidation Tests

When information is needed for settlement calculations on marine sediments (usually related to reclamation works), consolidation tests are usually carried out in oedometers with mechanical loading, although some hydraulic oedometers are also now available.

Because most sizeable buildings are founded on piles or caissons to bedrock, settlements are rarely a major design consideration (LUMB, 1972). When the compression characteristics of a residual soil are of importance to a design, these are usually quantified by triaxial data.

ACKNOWLEDGEMENTS

The Authors acknowledge the assistance of Mr G.W. Borrie and Mr D. Beaumont who made useful suggestions on the draft manuscript.

This Paper is published with the permission of the Director of Engineering Development of the Hong Kong Government.

REFERENCES

ALLEN, P.M. and STEPHENS, E.A. (1971). Report on the Geological Survey of Hong Kong. Govt. Printer, Hong Kong, 116 p. plus 2 maps.

ANDERSON, M.G. (1984). Prediction of Soil Suction for Slopes in Hong Kong. Geotech. Control Office, Hong Kong, 242 p.

ASSOCIATION OF ENGINEERING GEOLOGISTS (1978). A Guide to Core Logging for Rock Engineering. Bull. Assoc. Eng. Geol., Vol. 15, pp. 295-328.

BEATTIE, A.A. and CHAU, E.P.Y. (1976). The Assessment of Landslide Potential with Recommendations for Future Research. Hong Kong Engr., Vol. 4, No. 1, pp. 27-44. (Discussion, Vol. 4, No. 2, pp. 55-62).

BEATTIE, A.A. and MAK, B.L. (1982). Design and Construction of an Anchored-Buttress Caisson Retaining Wall. Proc. 7th S.E. Asian Geotech. Conf., Hong Kong, Vol. 1, pp. 465-480. (Discussion, Vol. 2, pp. 277-278).

BEATTIE, A.A. and YANG, C.M. (1982). The Design and Construction, by the Top Down Method, of an Industrial Building Supporting a 15 m Excavation. Proc. 7th S.E. Asian Geotech. Conf., Hong Kong, Vol. 1, pp. 481-495. (Discussion, Vol. 2, pp. 281).

BENJAMIN, A.L., ENDICOTT, L.J. and BLAKE, R.J. (1978). The Design and Construction of Some Underground Stations for the Hong Kong Mass Transit Railway System. Struct. Engr., Vol. 56A, pp. 11-20. (Discussion, Vol. 57A, 1979, pp. 231-237).

BERRY, L. (1957). Superficial Deposits of the Hong Kong Harbour Area. Hong Kong Univ. Eng. Jour., Vol. 21, pp. 38-50.

BISHOP, A.W. and HENKEL, D.J. (1962). The Measurement of Soil Properties in the Triaxial Test, 2nd edition. Edward Arnold, London, 236 p.

BORRIE, G.W., CIPULLO, A. and MASSEY, J.B. (1984). An Assessment of the British Code of Practice for Site Investigation for Hong Kong Conditions. Proc. 20th Regional Conf. Eng. Group, Geol. Soc. London, Guildford, pp. 65-76.

BRAND, E.W. (1981). Some Thoughts on Rain-induced Slope Failures. Proc. 10th Int. Conf. Soil Mech. Found. Eng., Stockholm, Vol. 3, pp. 373-376.

BRAND, E.W. (1982). Analysis and Design in Residual Soil. Proc. ASCE Spec. Conf. Engineering and Construction in Tropical and Residual Soils, Honolulu, pp. 89-146.

BRAND, E.W. (1984). Landslides in Southeast Asia: a State-of-the-art Report. Proc. 4th Int. Symp. Landslides, Toronto, Vol. 1, pp. 17-59. (Addendum, Vol. 3, in press).

BRAND, E.W. (1985). Bibliography on the Geology and Geotechnical Engineering of Hong Kong to December 1984. Geotechnical Control Office, Hong Kong, 76 p.

BRAND, E.W., BORRIE, G.W. and SHEN, J.M. (1983a). Field Measurements in Hong Kong Residual Soils. Proc. Int. Symp. Field Measurements in Geomechanics, Zurich, Vol. 1, pp. 639-648.

BRAND, E.W., BURNETT, A.D. and STYLES, K.A. (1982a). The Geotechnical Area Studies Programme in Hong Kong. Proc. 7th S.E. Asian Geotech. Conf., Hong Kong, Vol. 1, pp. 107-123.

BRAND, E.W., DALE, M.J. and NASH, J.M. (1984a). Discussion on "Soil Pipes and Slope Stability" by T.C. Pierson. Quart. Jour. Eng. Geol., Vol. 17, in press.

BRAND, E.W., HENCHER, S.R. and YOUDAN, D.G. (1983b). Rock Slope Engineering in Hong Kong. Proc. 5th Int. Rock Mech. Cong., Melbourne, Vol. 1, pp. C17-C24.

BRAND, E.W. and PHILLIPSON, H.B.(1985). Site Investigation Practice in Hong Kong. Site Investigation Manual, Int. Soc. Soil Mech. Found. Eng., Tokyo, in press.

BRAND, E.W., PHILLIPSON, H.B., BORRIE, G.W. and CLOVER, A.W. (1983c). In-situ Shear Tests on Hong Kong Residual Soils. Proc. Int. Symp. Soil and Rock Investigations by In-situ Testing, Paris, Vol. 2, pp. 813-817.

BRAND, E.W., PREMCHITT, J. and PHILLIPSON, H.B.(1984b). Relationship between Rainfall and Landslides in Hong Kong. Proc. 4th Int. Symp. Landslides, Toronto Vol. 1, pp. 377-384.

BRAND, E.W., STYLES, K.A. and BURNETT, A.D. (1982b). Geotechnical Land Use Maps for Planning in Hong Kong. Proc. 4th Cong. Int. Assoc. Eng. Geol., New Delhi, Vol. 1, pp. 145-153.

BRENNER, R.P. and PHILLIPSON, H.B. (1979). Sampling of Residual Soils in Hong Kong. Proc. Int. Symp. Soil Sampling, Singapore, pp. 109-120.

BRIAN-BOYS, K.C. and HOWELLS, D.J. (1984a). Model Specification for Prestressed Ground Anchors. Geotech. Control Office, Hong Kong, 127 p.

BRIAN-BOYS, K.C. and HOWELLS, D.J. (1984b). Prestressed Ground Anchor Practice in Hong Kong. Proc. Int. Conf. In Situ Soil and Rock Reinforcement, Paris, pp. 231-236.

BRITISH STANDARDS INSTITUTION (1975). Methods of Testing Soils for Civil Engineering Purposes: BS 1377. Brit. Stands Inst., London, 234 p.

BRITISH STANDARDS INSTITUTION (1981). Code of Practice for Site Investigation: BS 5930. Brit. Stands Inst., London, 147 p.

BURNETT, A.D. and STYLES, K.A. (1982). An Approach to Urban Engineering Geological Mapping as Used in Hong Kong. Proc. 4th Cong. Int. Assoc. Eng. Geol., New Delhi, Vol. 1, pp. 167-176.

CHAPPELL, B.A. and TONGE W.A. (1975). Investigations for the Aberdeen Tunnel. Tunnels & Tunnelling, Vol. 7, No. 6, pp. 52-54.

CHIANG, Y.C. and HO, Y.M. (1980). Pressuremeter Method for Foundation Design in Hong Kong. Proc. 6th S.E. Asian Conf. Soil Eng., Taipei, Vol. 1, pp. 31-42.

CHIPP, P.N., CLARE, D.G., HENKEL, D.J. and POPE, R.G. (1982). Field Measurement of Suction in Colluvium. Covered Slopes in Hong Kong. Proc. 7th S.E. Asian Geotech. Conf., Hong Kong, Vol. 1, pp. 49-962.

CHIU, T.N. and SO, C.L. (ed.) (1983). A Geography of Hong Kong. Oxford Univ. Press, Hong Kong, 299 p.

COWLAND, J.W. and THORLEY, C.B.B. (1984). Ground and Building Settlement Associated with Adjacent Slurry Trench Excavation. Proc. 3rd. Int. Conf. Ground Movements and Structures., Cardiff, in press.

DAVIES, R.V. and HENKEL, D.J. (1980). Geotechnical Problems Associated with the Construction of Chater Station, Hong Kong. Proc. Conf. Mass Transportation in Asia., Hong Kong, paper J3, 31 p.

DEERE, D.U. and PATTON, F.D. (1971). Slope Stability in Residual Soils. Proc. 4th Panam. Conf. Soil Mech. Found. Eng., San Juan, Puerto Rico, Vol. 1, pp. 87-170.

DE MELLO, V.F.B. (1972). Thoughts on Soil Engineering Applicable to Residual Soils. Proc. 3rd S. E. Asian Conf. Soil Eng., Hong Kong, pp. 5-34.

ELLIOTT, S.G. (1983). Near Shore Projects in Hong Kong. Proc. Symp. Geotechnical Aspects of Coastal and Offshore Structures, Bangkok, pp. 275-280.

ENDICOTT, L.J. (1982). Analysis of Piezometer Data and Rainfall Records to Determine Groundwater Conditions. Hong Kong Engr., Vol. 10, No. 9, pp. 53-56.

FABER, J.C. (1972). Introduction to "Symposium on Pier, Shaft and Caisson Foundations". Proc. 3rd S.E. Asian Conf. Soil Eng., Hong Kong, pp. 377-380. (Discussion, pp. 387)

FLINTOFF, W.T. and COWLAND, J.W. (1982). Excavation Design in Residual Soil Slopes. Proc. ASCE Spec. Conf. Engineering and Construction in Tropical and Residual Soils, Honolulu, pp. 539-556.

FOOTT, R. (1982). Moderator's Report on Settlement. Proc. 7th S.E. Asian Geotech. Conf., Hong Kong, Vol. 2, pp. 353-363.

FORTH, R.A. and PLATT-HIGGINS, P.M. (1981). Methods of Investigation of Weathered Rocks in Hong Kong. Proc. Int. Symp. Weak Rock, Tokyo, Vol. 2, pp. 519-526. (Discussion, Vol. 3, pp. 1387).

FREDLUND, D.G. (1981). The Shear Strength of Unsaturated Soil and Its Relationship to Slope Stability Problems in Hong Kong. Hong Kong Engr. , Vol. 9, No. 4, pp. 37-45. (Discussion, Vol. 10, No. 1, pp. 41-42 and No. 6, pp. 57-59,1982).

GEOLOGICAL SOCIETY OF HONG KONG (1983). Proceedings of the Meeting on Geology of Surficial Deposits in Hong Kong, Hong Kong, ed. W. W. S. Yim. Geol. Soc. Hong Kong, 183 p.

GEOLOGICAL SOCIETY OF HONG KONG (1984). Proceedings of the Conference on Geological Aspects of Site Investigation, ed. W.W.S. Yim. Geol. Soc. Hong Kong, in press.

GEOLOGICAL SOCIETY OF LONDON (1977a). The Logging of Cores for Engineering Purposes. Quart. Jour. Eng. Geol., Vol. 10, pp. 45-52.

GEOLOGICAL SOCIETY OF LONDON (1977b). The Description of Rock Masses for Engineering Purposes. Quart. Jour. Eng. Geol., Vol. 10, pp. 355-388.

GEOTECHNICAL CONTROL OFFICE (1982). Mid-levels Study: Report on Geology, Hydrology and Soil Properties. Geotech. Control Office, 266 p. plus 54 drgs.

GEOTECHNICAL CONTROL OFFICE (1984). Geotechnical Manual for Slopes, 2nd Edition. Geotech. Control Office, Hong Kong, 295 p.

HASWELL,C.K., UMNEY, A.R., HALL, P., HANSEN , F.J., STOREY F.G.,ARCHER, G.O. and LANGFIELD, R.A. (1980). Hong Kong Mass Transit Railway Modified Initial System : Design and Construction of the Driven Tunnels and the Immersed Tube. Proc. Inst. Civ. Engrs., Vol. 68, pp. 627-655. (Discussion, Vol. 72, 1982, pp. 87-98).

HENCHER, S.R. and MARTIN, R.P. (1982). The Description and Classification of Weathered Rocks in Hong Kong for Engineering Purposes. Proc. 7th S.E. Asian Geotech. Conf., Hong Kong, Vol. 1, pp. 125-142. (Discussion, Vol. 2, pp. 167-168).

HENCHER, S.R., MASSEY, J.B. and BRAND, E.W.

(1984). Application of Back Analysis to Some Hong Kong Landslides. Proc. 4th Int. Symp. Landslides, Toronto, Vol. 1, pp. 631-638.

HENCHER, S.R. and RICHARDS, L. (1982). The Basic Frictional Resistance of Sheeting Joints in Hong Kong Granite. Hong Kong Engr., Vol. 11, No. 2, pp. 21-25.

HO, D.Y.F. and FREDLUND, D.G. (1982a). Increase in Strength due to Suction for Two Hong Kong Soils. Proc. ASCE Spec. Conf. Engineering and Construction in Tropical and Residual Soils, Honolulu, pp. 263-295.

HO, D.Y.F. and FREDLUND, D.G. (1982b). A Multistage Triaxial Test for Unsaturated Soils. Geotech. Testing. Jour., Vol. 5, pp. 18-25.

HOEK, E. and BRAY, J.W. (1977). Rock Slope Engineering, 2nd Edition. Inst. Min. & Met., London, 402 p.

HONG KONG JOINT GROUP (1962). Proceedings of the Symposium on Hong Kong Soils, Hong Kong, ed. P. Lumb. Hong Kong Joint Group Insts. Civ., Mech. & Elec. Engrs, Hong Kong, 149 p. plus 18 drgs.

HUNT,T., KEMP, W.R. and KOO, Y.C. (1982). Castle Peak Bay Reclamation, Hong Kong. Proc. 7th S.E. Asian Geotech. Conf, Hong Kong, Vol. 1, pp. 257-269.

HUNTLEY, S.L. and RANDALL, P.A.(1981). Recognition of Colluvium in Hong Kong. Hong Kong Engr., Vol. 9, No. 12, pp. 13-18.

JANBU, N. (1954). Application of Composite Slip Surface for Stability Analysis. Proc. Europ. Conf. Stability of Earth Slopes, Stockholm, Vol. 3, pp. 43-49.

JANBU, N. (1973). Slope Stability Computations. Embankment Dam Engineering (Casagrande Volume), ed. R.C. Hirschfeld & S.J. Poulos, pp. 47-107. Wiley, New York.

KOO, Y.C. (1982). The Mass Strength of Jointed Residual Soils. Canad. Geotech. Jour., Vol. 19, pp. 225-231.

KOO, Y.C. and LUMB, P. (1981). Correlation between Rainfall Intensities and Groundwater Levels in the Natural Slopes of Hong Kong. Hong Kong Engr., Vol. 9, No. 10, pp. 49-52.

LEACH, B. and HERBERT, R. (1982). The Genesis of a Numerical Model for the Study of the Hydrogeology of a Steep Hillside in Hong Kong. Quart. Jour. Eng. Geol., Vol. 15, pp. 243-259.

LINNEY, L.F.(1983). A Review of the Geotechnical Aspects of the Construction of the First Phase of the Mass Transit Railway, Hong Kong. Quart. Jour. Eng. Geol., Vol. 16, pp. 87-102.

LUMB, P. (1962a). General Nature of the Soils of Hong Kong. Proc. Symp. on Hong Kong Soils, Hong Kong, pp. 19-23.

LUMB, P. (1962b). The Properties of Decomposed Granite. Géotechnique, Vol. 12, pp. 226-243 (plus 2 plates).

LUMB, P. (1964). Multi-stage Triaxial Tests on Undisturbed Soil. Civ. Eng. and Pub. Works Review, Vol. 59, pp. 591-595.

LUMB, P. (1965). The Residual Soils of Hong Kong. Géotechnique, Vol. 15, pp. 180-194. (Discussion, Vol. 16, 1966, pp. 78-81 and 359-360).

LUMB, P. (1972). Building Settlements in Hong Kong. Proc. 3rd S.E. Asian Conf. Soil Eng., Hong Kong, pp. 115-211. (Discussion, pp. 394-396).

LUMB, P. (1975). Slope Failures in Hong Kong. Quart. Jour. Eng. Geol., Vol. 8, pp. 31-65.

LUMB, P. (1976). Land Reclamation in Hong Kong. Proc. Residential Workshop on Materials and Methods for Low Cost Road, Rail and Reclamation Works, Leura, Austalia, pp. 299-314.

LUMB, P. (1977). The Marine Soils of Hong Kong and Macau. Proc. Int. Symp. Soft Clay, Bangkok, pp. 45-58.

LUMB, P. (1979). Building Foundations in Hong Kong, Proc. 6th Asian Reg. Conf. Soil. Mech. Found. Eng., Singapore, Vol. 2, pp. 211-214.

LUMB, P. (1983). Engineering Properties of Fresh and Decomposed Igneous Rocks from Hong Kong. Eng. Geol., Vol. 19, pp. 81-94.

LUMB, P. and HOLT, J.K.(1968). The Undrained Shear strength of a Soft Marine Clay from Hong Kong. Géotechnique, Vol. 18, pp. 25-36.

MACKEY, S. and YAMASHITA, T. (1967). Experiences with Caissons and Pier Foundations in Hong Kong. Proc. 1st S.E. Asian Regional Conf. Soil Eng., Bangkok, pp. 301-312.

MAZIER, G. (1974). Methodes de Prélèvement des Sols Meubles. Annales dè l'Institut Technique du Bâtiment et des Trauvaux Publics, No. 319, pp. 79-85.

McFEAT-SMITH, I. (1982). Geotechnical Feasibility Study and Site Investigation for the Western Aqueduct Tunnels, Hong Kong. Proc. 7th S.E. Asian Geotech. Conf., Hong Kong Vol. 1, pp. 171-187.

McINTOSH, D.F,, WALKER, A.J.R., EASTWOOD, D.J., IMAMURA, M. and DOHERTY, H. (1980). Hong Kong Mass Transit Railway Modified Initial System: Design and Construction of Underground Stations and Cut-and-cover Tunnels. Proc. Inst. Civ. Engrs., Vol. 68, pp. 599-626. (Discussion, Vol. 72, 1980, pp. 87-98).

MICHAEL D., WAN, T.K.C. and HANNON, J. (1981). Hopewell Centre, Hong Kong. Struct. Engr., Vol. 59A, pp. 17-26.

MIRTL, H. (1977). Diamond Drilling in Hong Kong. Proc. De Beer's International Industrial Diamond Convention, Manila, pp. 16.1-16.4.

MIRTL, H. (1979). Drillability of Hong Kong Granites. Proc. De Beer's Seminar, Hong Kong, 5 p .

MORTON, K. and TSUI, P. (1982). Geotechnical

Aspects of the Design and Construction of the Basement of the China Resources Building, Wanchai. Proc. 7th S.E. Asian Geotech. Conf., Hong Kong, Vol. 1, pp. 529-543.

MOYE, D.G. (1955). Engineering Geology for the Snowy Mountains Scheme. Jour. Inst. Engrs. Australia, Vol. 27, pp. 287-298.

NASH, J.M. and DALE, MJ. (1983). Geology and Hydrogeology of Natural Tunnel Erosion in Superficial Deposits in Hong Kong. Proc. Hong Kong Geol. Soc. Meeting, Geology of Surficial Deposits in Hong Kong, Hong Kong, pp. 61-72.

OPENSHAW, P.J. and MARCHINI, H.F. (1980). Diaphragm Wall Construction in Hong Kong Soil Conditions. Proc. Conf. Mass Transportation in Asia, Hong Kong, paper J4,20 p.

PECK, R.B. (1969). Advantages and Limitations of the Observational Method in Applied Soil Mechanics. (9th Rankine Lecture). Géotechnique, Vol. 10, pp. 171-18.

PHILLIPSON, H.B. and BRAND, E.W. (1985). Sampling and Testing of Residual Soils in Hong Kong: Sampling and Testing of Residual Soils: A Review of International Practice, ed. E.W. Brand & H.B. Phillipson, in press. Scorpion Press, Hong Kong.

PHILLIPSON, H.B. and CHIPP, P.N. (1981). High Quality Core Sampling-Recent Development in Hong Kong. Hong Kong Engr., Vol. 9, No. 4, pp. 9-15.

PHILLIPSON, H.B. and CHIPP, P.N. (1982). Air Foam Sampling of Residual Soils in Hong Kong. Proc. ASCE Spec. Conf. Engineering and Construction in Tropical and Residual Soils, Honolulu, pp. 339-356.

PIERSON, T.C. (1983). Soil Pipes and Slope Stability. Quart. Jour. Eng. Geol., Vol. 16, pp. 1-11.

POPE, R.G., WEEKS, R.C. and CHIPP, P.N.(1982). Automatic Recording of Standpipe Piezometers. Proc. 7th S.E. Asian Geotech. Conf., Hong Kong, Vol. 1, pp. 77-89.

RICHARDS, L.R. and COWLAND, J.W. (1982). The Effect of Surface Roughness on the Field Shear Strength of Sheeting Joints in Hong Kong. Hong Kong Engr., Vol. 10, No. 10, pp. 39-43.

RIDLEY-THOMAS, W.N. (1982). The Application of Engineering Geophysical Techniques to Site Investigations in Hong Kong. Proc. 7th S.E. Asian Geotech. Conf., Hong Kong, Vol. 1, pp. 205-226.

RODIN, S., HENKEL, D.J. and BROWN, R.L. (1982). Geotechnical Study of a Large Hillside Area in Hong Kong. Hong Kong Engr., Vol. 10, No. 5, pp. 37-45.

RUXTON, B.P. (1960). The Geology of Hong Kong. Quart. Jour. Geol. Soc. London, Vol. 115, pp. 233-260 (plus 2 plates & 1 map).

RUXTON, B.P. and BERRY, L.(1957). Weathering of Granite and Associated Erosional Features in Hong Kong. Bull. Geol. Soc. Amer., Vol. 68, pp. 1263-1291 (plus 1 plate).

SALAS, J.A.J. (1977). ‘Concluding Remarks’. Proc. Specialty Session on Soil Sampling, 9th Int. Conf. Soil Mech. Found. Eng., Tokyo, Vol. 2, pp. 37-41.

STYLES, K.A., BURNETT, A.D. and COX, D.C. (1982). Geotechnical Assessment of the Terrain for Land Management and Planning Purposes in Hong Kong. Proc. 1st Int. Symp. Soil, Geology and Landforms : Impact on Land Use Planning in Developing Countries, Bangkok, pp. F16.1-F16.9.

SWEENEY, D.J. (1982). Some in situ Soil Suction Measurements in Hong Kong's Residual Soil Slopes. Proc. 7th S.E. Asian Geotech. Conf., Hong Kong, Vol. 1, pp. 91-106. (Discussion, Vol. 2, pp. 93-96).

SWEENEY, D.J. and HO, C.S. (1982). Deep Foundation Design Using Plate Load Tests. Proc. 7th. S.E. Asian Geotech. Conf., Hong Kong, Vol. 1, pp. 439-452.

TAMARO,G.(1981). Perimeter Wall for New World Centre, Hong Kong. Jour. Construct. Div., ASCE, Vol. 107, pp. 193-207.

TREGEAR, T.R. and BERRY, L. (1959). The Development of Hong Kong and Kowloon as Told in Maps. Hong Kong Univ. Press, 35 p. plus 1 map.

VAIL, A.J. and HOLMES, D,G. (1982). A Retaining Wall in Hong Kong. Proc. 7th S.E. Asian Geotech. Conf., Hong Kong, Vol. 1, pp. 557-570. (Discussion, Vol. 2, pp. 283).

WALKER, L.K., CHANDLER, B.C. and LUMB, P.(1972). Site Investigation of a Deeply Weathered Soil Profile. Proc. 3rd S.E. Asian Conf. Soil Eng., Hong Kong. pp. 73-78. (Discussion, pp. 392-393).

WONG, H.Y. (1978). Soil Strength Parameter Determination. Hong Kong Engr., Vol. 6, No. 3, pp. 33-39. (Discussion, Vol. 6, No. 6. pp. 37-38 and No. 7, pp. 34).

WONG, H.Y. (1982). An Evaluation of Various Methods of Triaxial Testing and Analysis for Residual Soils in Hong Kong. Proc. 7th S.E. Asian Geotech. Conf., Hong Kong, Vol. 1, pp. 901-913.