Proceedings of the Seventh Southeast Asian Geotechnical Conference / 22-26 November 1982 / Hong Kong

THE DESCRIPTION AND CLASSIFICATION OF WEATHERED ROCKS IN HONG KONG FOR ENGINEERING PURPOSES

S. R. Hencher
Geotechnical Control Office
Hong Kong

R. P. Martin
Geotechnical Control Office
Hong Kong

SUMMARY Despite recent advances in the standardisation of geotechnical descriptions of soils and rocks, the particular problem of characterising thick zones of weathering has not been adequately covered. Many of the classification schemes that have been proposed for such materials are poorly defined and therefore of limited practical use.

In this paper, methods of description are presented that rely heavily on simple index tests to encourage objectivity. Using these index tests, a classification scheme for weathered materials in Hong Kong has been established, and the field characteristics of each weathering grade are examined statistically. Finally an example is given which demonstrates how the field index tests can be applied directly to engineering problems.

INTRODUCTION

Consistent and objective description of materials is important for good site investigation to allow the design engineer to understand exactly what has been identified in the field. A number of learned societies have recently published recommendations for materials description and it is encouraging that there is now a great deal of uniformity in the terms used and in their definitions (ANON, 1970, 1972, 1977, 1979; ISRM, 1978, 1981). The terms given for the description of weathered rocks in these publications, however, are rather general and do not adequately characterise the variable nature of the thick zones of weathering commonly encountered in tropical and subtropical regions. As a result, the description of weathered rocks is still of a qualitative nature and largely a matter of individual judgement.

Many authors have described weathered rocks by setting up classification schemes based on zones of decomposition which encompass mass properties together with material properties. In many of these classifications, the zonal characteristics are poorly defined and this limits their usefulness in areas away from the type locality. Similarly many of these schemes are not comprehensive and this leads to difficulties when exposures are encountered which do not readily fit the classification. Recently, more quantitative methods of description have been proposed for these materials (e.g. BAYNES & DEARMAN, 1978; IRFAN & DEARMAN, 1978) and these are discussed in some detail in the paper.

The aim of this paper is to propose an objective method for the field description of weathered materials commonly found in Hong Kong and to present a materials classification scheme based on simple index tests. This classification, when combined with the concept of layers discussed later, provides a framework for delineating a particular weathering profile into zones of distinct engineering characteristics. It is suggested that this procedure has widespread application.

GENERAL APPROACH

The need for an improved method of describing weathered materials became clear during the recent CHASE study carried out by the Geotechnical Control Office. The aim of this study was to investigate the application of empirical rules for the design of cut slopes in Hong Kong (BRAND, 1982; BRAND & HUDSON, 1982). A data bank was compiled for 177 cut slopes of up to 50 metres in height covering all the factors considered to be relevant to slope stability in weathered rocks and soils. No subsurface investigation apart from dynamic probing was carried out specifically for this study, although where such information was available it was incorporated within the data bank. In order to quantify the engineering properties of the materials encountered, total reliance was placed on field descriptions. In view of the empirical framework, it was essential that materials should be described consistently and accurately to facilitate classification during data analysis.

From the outset it was considered important to avoid notions of 'type' weathering profiles as commonly reported in the literature so that anomalous exposures would not be excluded. The descriptive method is based on three key assumptions viz :-

i) All sub-surface profiles can be subdivided into one or more layers or zones, each of which have distinctive engineering properties.

ii) The descriptive terms commonly used to characterise the engineering properties of a particular layer can be made more objective by incorporating simple index tests into the field procedure.

iii) Materials containing large fragments of relatively stronger material (e.g. decomposed granite with corestones or bouldery colluvium) can be best treated by describing both the matrix (fine fraction) and fragments (coarse fraction) separately and fully.

The first of these points has been widely discussed in the literature and forms the basis for most of the well-known classifications of weathered rocks.

DEERE & PATTON (1971) gave a good summary of several different schemes covering a range of igneous and metamorphic rocks. Clearly, repeated field observations of different layers within the same profile have been the prime reason for the widespread use of the 'weathering zone' concept. However the precision with which layer boundaries can be defined varies widely between different rock types at the regional scale and often within one rock type at the local scale of a construction site. Therefore it is important to consider whether the continuing use of layers as based on an idealised weathering profile may be more a matter of convenience in subdividing thick profiles into manageable units, rather than representing real differences of engineering significance between layers.

DE MELLO (1972) has argued that the accuracy with which layer boundaries of the weathering profile type are established is often too small to be of real benefit in engineering design and construction. He prefers to regard the typical weathering profile as a continuum in which average engineering properties vary gradually with depth, but accepts that it is often possible to define three significant horizons - the upper mature soil, the intermediate residual soil and the lower weathered rock. Even if this is accepted as the most useful general subdivision, inconsistencies between different schemes are apparent. For example both DEERE & PATTON (1971) and DE MELLO (1972) consider saprolitic material containing relict structures as "residual soil", whereas the term is often used in the more restricted context of *in situ* structureless soils (e.g. ANON, 1972, 1977).

Based on field experience in Hong Kong and for the specific purposes of the CHASE study, it was decided that layers would be described not on the basis of a poorly defined and often incomplete weathering profile but on the basis of variations in engineering properties as defined by index tests and quantitative estimates. The procedure for distinguishing between layers was made flexible enough to allow for all possible material types and combinations of materials.

The third point relating to 'two-phase' materials is of particular relevance in the description of transported soils and rocks characterised by corestone-type weathering. Some schemes assign layer boundaries on the basis of the coarse fraction or rock percentage being greater or less than 50% (e.g. RUXTON & BERRY, 1957; DEARMAN, 1974). It is questionable whether this value represents the most appropriate cut-off point, particularly for studies of slope stability. In the scheme proposed here, separate descriptions of both components have been incorporated as a basic requirement, which includes an estimate of the actual percentage of coarse fraction in each layer as otherwise defined. The criteria for delineation of layers are discussed fully in the following section.

QUANTITATIVE FIELD DESCRIPTION OF WEATHERED ROCKS

Introduction

The scope of the descriptive method developed for the CHASE study is similar to the standard schemes for field engineering geological description as given in the Geological Society Engineering Group Working Party Reports (ANON, 1972, 1977) and BS 5930 (BRITISH STANDARDS INSTITUTION, 1981). The distinctive feature of the method proposed here is the greater use of simple index tests and quantitative estimates, both to assist in the definition of weathering grades and to indicate specific engineering properties. Such tests may be either quantitative, where the test gives a result on a numbered continuous scale, or semi-quantitative where a number of groups or classes are defined.

The field procedure adopted for describing existing cut slope profiles was to split the profiles initially into distinct layers on the basis of material properties (such as Schmidt hammer rebound value) and mass properties (such as the coarse fraction percentage). Representative areas of both the fine and coarse fractions within each layer were then described fully, together with layer and slope attributes. Although this procedure was developed for the description of exposed materials, the majority of the tests can also be used to help quantify the nature of materials obtained from boreholes.

Material Attributes

The main tests and descriptive terms used are summarised in Table I and are discussed below. As a general point, it should be noted that practically all the tests were carried out for this study on samples in an unsaturated condition. The effect of the initial moisture content on the test values, although possibly of importance, has not been investigated.

a) Colour - The method proposed here is more objective than the simplified scheme recommended by the Geological Society Working Party Reports (ANON, 1972, 1977) and has the added advantage that several different colours are recorded for mottled materials. For the CHASE study, 14 colours, representing the most commonly occurring colours in the weathered materials of Hong Kong, were selected from the Munsell Soil Colour Chart (MUNSELL, 1975) and glued to a wooden scale for use in the field.

b) Grain size and texture - Where the original rock texture is preserved in a material that is essentially soil-like in its properties, it is important to record the relict texture. The particle size distribution of the remoulded material should also be recorded and although this can be estimated in the field, for the CHASE study, sieve analysis was carried out in the laboratory. The percentile diameters were chosen to comply with those used by LUMB (1962, 1965) to describe residual soils in Hong Kong.

c) Microfractures - Microfracturing can result from gradual mechanical weathering (DEARMAN, 1974), from elastic rebound due to stress relief (NICHOLS, 1980) or from tectonic activity (NEWBERRY, 1971; BERRY ET AL, 1978) and all three types can be recognised in Hong Kong. The simple descriptive scheme presented here is far less comprehensive than the detailed account of physical disintegration given by DEARMAN (1974), but has the advantage that microfracturing (a materials feature) is separated from jointing (a mass feature) and is considered more practical for field use. Microfracturing has an important effect on the physical properties of rock (BERRY ET AL, 1978; IRFAN & DEARMAN, 1978) and must be taken into account when assessing the results of index tests. Microfractures in the form of rebound fractures can cause planar slope failure and the dip and azimuth of parallel microfractures should be recorded.

TABLE I FIELD TESTS FOR DESCRIPTION OF WEATHERED MATERIALS

SCALE	ATTRIBUTE	TEST	PROCEDURE	CLASSES/TERMS
MATERIALS	COLOUR	COLOUR	Hand specimen. Note if material is uniform or mottled. Record colours in order of importance as identified from standard colour charts.	
	GRAIN SIZE AND TEXTURE	GRAIN SIZE	Hand specimen. Refers to ORIGINAL rock texture. Record texture and grain size of groundmass. In the case of colluvium and grade VI residual soil this item is not applicable.	1. Equigranular (all grains about the same size) 2. Porphyritic (relatively large grains in a finer ground mass) 3. Inequigranular (grain size variable) 1. Coarse (>2mm) 2. Medium (0.06mm to 2mm) 3. Fine (<0.06mm)
		PARTICLE SIZE DISTRIBUTION	In weak materials (grades IV-VI and colluvium) take 3 kg sample and wet sieve to produce a particle size distribution curve.	% Fines, % Sand 025, 050, 075
	STRUCTURE	MICROFRACTURES	Hand specimen. Record degree of microfracturing.	1. No microfractures 2. Minor microfractures 3. Extensive microfractures resulting in friable rock.
	COHESION	SLAKEABILITY	Immerse small sample (eg: 75mm diameter) in water. If sample does not slake in a few minutes agitate the container gently.	1. Does not slake 2. On agitation breaks down to discrete fragments 3. On agitation breaks down to a slurry. 4. Slakes completely.
	STRENGTH	FIELD TEST STRENGTH ESTIMATE	1. Easily penetrated several inches by thumb. 2. Penetrated several inches by thumb with effort. 3. Indented with thumb. 4. Readily indented with thumbnail. 5. Indented with thumbnail with difficulty 6. Not indented with thumbnail. Easily peeled with knife. 7. Crumbles under firm blows with geological pick. 8. Shallow indentations with pick. 9. Not peeled with knife. No indentation with pick.	1. Soft 2. Firm 3. Stiff 4. Very stiff 5. Hard 6. Extremely soft rock 7. Very soft rock 8. Soft rock 9. Hard rock
		HAND PENETROMETER STRENGTH	Using a standard hand penetrometer, take an average of 10 values of cohesion avoiding disturbed or friable areas.	0 - 250 kN/m^2 If too strong record as 300
		N SCHMIDT HAMMER REBOUND VALUE	After "seating" blows, take the average of the highest five of ten blows at the same location. Estimate values between 0 and 10. Only record as zero if there is NO rebound.	Rebound value (N)
	INFILTRATION POTENTIAL	INFILTRATION	Drive 100mm diameter cylinder until firmly anchored in prepared horizontal platform. Fill with water to 800mm above ground surface.	Record time for head loss of 300mm. If greater than 30 minutes record head loss (mm) in 30 minutes.
	DECOMPOSITION	FELDSPAR STRENGTH	Scratch feldspar with a pin. Where feldspars are in various states of decomposition record nature of dominant type.	1. Not scratched 2. Just scratched 3. Easily grooved 4. No feldspars
		DECOMPOSITION GRADE	Record decomposition grade as indicated by criteria given in Table II	Six grades (see Table 2)
LAYERS	LAYER GRADING	COARSE FRACTION PERCENTAGE	Within a distinct layer estimate the percentage of corestones or contained fragments larger than 0.06m diameter.	Nearest 10%
		COARSE FRACTION GRADING	Select code which most closely represents the distribution of boulder and cobble sized fragments within the layer.	1. Boulders larger than 0.6m 2. Boulders 0.2m to 0.6m 3. Cobbles 0.06m to 0.2m 4. Mixed
		COARSE FRACTION ANGULARITY	Typical angularity of coarse fraction.	1. Rounded 2. Sub rounded 3. Angular
	STRUCTURE	JOINTING PATTERN	Select code which most closely represents the jointing pattern within the layer. Planar failure can occur where a joint dips at greater than 20° with dip direction ± 10° of the azimuth of the slope. Wedge failure can occur where the line of intersection dips at greater than 20° and daylights. Record joint details separately.	1. Widely spaced. Not adverse 2. Blocky. Spacing >500mm. Not adverse 3. Blocky. Spacing <500mm. Not adverse 4. Potential wedge failure 5. Potential planar failure 6. Potential toppling failure 7. Potential complex failure
SLOPE	ROCK TYPE	ROCK TYPE	Select rock type from table given in BS 5930 (1981) on the basis of mineralogy and texture.	Rock type
	PROFILE	PROFILE	Select profile that most closely represents the distribution of layers within the slope.	12 profiles as reproduced by Brand (1982)

d) Slakeability - The slake test gives an indication of the degree of cohesion within the material. TERZHAGI & PECK (1967) used the test to distinguish between engineering soil and rock, and MOYE (1955) and IRFAN & DEARMAN (1978) also used it to help define weathering grades. The slake test proved extremely helpful for distinguishing between decomposition grades IV and V in the classification discussed below.

e) Feldspar strength - The clearest indication of decomposition in many igneous rocks is given by the alteration of feldspars, and several authors have used this feature as a means of discriminating between different degrees of decomposition (IRFAN & DEARMAN, 1978; BERRY ET AL, 1978). In a more quantitative manner, LUMB (1962) defined a decomposition index for granite, Xd, which is a measure of the changing quartz/feldspar ratio during weathering. However, the determination of Xd requires accurate identification of feldspars and time-consuming laboratory testing which prohibits its use as a rapid index test.

f) Field test strength estimate - A modified version of a hardness scale produced by PITEAU (1970) and similar to that given by ANON (1977) is recommended.

g) Hand penetrometer strength - This test is best suited to weaker materials with a high fines content. The presence of residual quartz in decomposed coarse-grained rocks can result in wide variation. An approximate value for 'cohesion' is obtained by dividing the instrument reading (uniaxial compressive strength) by 2. The recommendation that a value of 300 kN/M^2 be recorded for materials too strong for a reading to be taken is to allow the calculation of a shear strength index as explained in the example given at the end of this paper. To avoid possible confusion, users may wish to simply record results from strong materials as greater than 250 kN/M^2 (the limit of most instruments).

h) N Schmidt hammer rebound value - The use of Schmidt hammers has generally been restricted to rocks in the strong to very strong range (ANON, 1977). IRFAN & DEARMAN (1978) quoted rebound values for all weathering grades but implied that it is not a reliable test for very weak rocks and soils. Field trials for this study revealed that there is a correlation between decomposition grade as otherwise defined and rebound value over the full weathering scale. Materials of grade V and VI do not normally give any rebound value whereas a positive value is usually recorded for grade IV providing the rock is not highly jointed or microfractured. For the CHASE study, similar tests were carried out using the lower-energy 'L' hammer. Experience showed, however, that the 'N' hammer gave more consistent results and required less servicing.

i) Decomposition grade - Weathered rocks in Hong Kong are normally classified into decomposition grades in accordance with a scheme adopted by the GEOTECHNICAL CONTROL OFFICE (1979) and based on that developed for the Snowy Mountains Scheme in Australia (MOYE, 1955). These grades are based predominantly on chemical rather than mechanical weathering.

Following a review of other classification schemes, the authors decided to include a classification similar to that used by the GCO as an extra item

in the checklist, but to define the grades more precisely on the basis of index tests. This was necessary as the original definitions are loose and commonly lead to ambiguous description.

Initial field trials were conducted to determine the range of index test results within each decomposition grade as otherwise defined. These trials showed that no single index was sufficient to define the limits between grades but that groups of indices together could define the grade changes quite clearly. They also showed that the same grade definitions could be applied to both granitic and volcanic rocks. The redefined classification scheme is given in Table II and this was used successfully throughout the CHASE study. It might be noted that where description is being made for a specific engineering purpose, properties other than those used in Table II could be more relevant, in which case other groupings should be considered. Such properties might include microfracturing or infiltration index; alternatively materials could be grouped according to laboratory test results.

TABLE II CLASSIFICATION OF WEATHERED GRANITE AND VOLCANIC ROCKS IN HONG KONG

GRADE AND DESCRIPTION	TYPICAL CHARACTERISTICS
I FRESH ROCK	• No visible signs of weathering • Rarely encountered in surface exposures
II SLIGHTLY DECOMPOSED ROCK	• N Schmidt rebound value greater than 45 • More than one blow of geological hammer to break specimen • Strength approaches that of fresh rock
III MODERATELY DECOMPOSED ROCK	• N Schmidt rebound value 25 to 45 • Considerably weathered but possessing strength such that pieces 55mm diameter cannot be broken by hand • Rock material is not friable
IV HIGHLY DECOMPOSED ROCK	• N Schmidt rebound value 0 to 25 • Does not slake readily in water • Geological pick cannot be pushed into surface • Hand penetrometer strength index greater than 250kN/m^2 • Rock weakened so that large pieces can be broken by hand • Individual grains may be plucked from the surface
V COMPLETELY DECOMPOSED ROCK	• No rebound from N Schmidt hammer • Slakes readily in water • Geological pick easily indents when pushed into the surface • Rock is wholly decomposed but the rock texture is preserved
VI RESIDUAL SOIL	• A soil mixture with the original texture of the rock completely destroyed

j) Infiltration - The test is a crude falling-head test using a 100 mm diameter steel cylinder. The water level was indicated in a small plastic pipe with a metal end welded to the base of the cylinder. Because of the large head of water, the short duration of the test and the absence of a ponded buffer zone to encourage vertical seepage it was thought unlikely that the results would give an accurate indication of limiting infiltration rates during intense rainstorms. However, a number of check tests using a portable constant-head infiltrometer of the type described by HILLS (1968) were also carried out. A comparison of the results from these tests suggested that the falling-head test does give a reasonable approximation to limiting infiltration rates. The implication of these findings is that the test may give a fairly accurate indication of *in situ* permeabilities.

Layer Attributes

The materials tests discussed above are generally applicable to hand-sized specimens. For engineering purposes, a complete description must also take into account mass properties of the materials, in particular the way in which materials are grouped within a sub-surface profile. Materials should be split into layers which represent zones of material that can be considered as uniform in their engineering characteristics and distinct from other layers above or below. The characteristic feature used to distinguish one layer from another could be rock type, decomposition grade, percentage of corestones or boulders, microfracturing, slakeability or any of the other material properties recorded, provided it is considered important enough a distinction for engineering purposes. This layer concept is analogous to the observational method used by RUXTON & BERRY (1958) and many others to divide sub-surface profiles into zones, but the important difference is that layer definition is not conditioned by the rigid framework of an idealized weathering profile in which the degree of weathering always decreases with depth. As pointed out by FOOKES & HORSWILL (1970) and DEARMAN (1974), anomalous conditions of relatively unweathered rock underlain by more altered material are often encountered. The distribution of the six weathering grades within the rock mass is often determined by geological factors and not necessarily topographical factors alone.

A number of specific layer attributes were recorded for the CHASE study. These are as follows :-

a) Coarse fraction percentage - The coarse fraction is defined as the contained fragments larger than gravel size and of distinctly different material properties from the fine fraction (matrix).

For slope stability problems, a content of 30% is an appropriate limit for separating layers as it can be shown by idealised diagrams that where the coarse fraction percentage is greater than this, extensive failure cannot occur through the matrix without shearing of harder fragments or significant dilation occurring. RUXTON & BERRY (1957) separated layers on a 50% corestone content, as did DEARMAN (1974) on the basis of the potential for rotation of blocks and hence ease of excavation.

b) Coarse fraction grading and angularity - These properties describe the size and shape of the coarse fraction.

c) Other coarse fraction properties - A complete material description as given in Table I should be carried out on a representative sample from the

coarse fraction. However, due to the often variable nature of the contained fragments, an estimate should also be made of the percentage of the coarse fraction typified by the described sample.

d) Jointing pattern - Jointing pattern should be described by selecting the code which most closely represents the nature of the joints within the layer. The first three groups are based on the work of HOEK & BROWN (1980) who have developed empirical strength criteria for a number of major rock types subdivided into six classes defined primarily by different joint spacings. For slope stability problems, joint codes 4-7 inclusive (which imply a definite potential failure mode) should take precedence over codes 1-3 where they are equally applicable to a layer. Where potential failure planes are identified, full descriptions should be made in accordance with the ISRM (1978, 1981) recommendations.

Slope Attributes

These attributes are applicable to complete profiles, which may comprise more than one layer.

a) Rock type - For non-geologists, the simplified classification given in BS 5930 (BRITISH STANDARDS INSTITUTION, 1981) is probably the most practical for field use. For Hong Kong, however, due to the widespread occurrence of various rock types that all fall into the single class of granite in this scheme, it is better to classify rock type more precisely where possible. In the case of colluvial profiles, the predominant rock type of the coarse fraction should be identified. Individual layers should be classified as either *in situ*, transported or fill; where the geology is complex, rock type should be recorded for each layer.

b) Profile - A series of twelve profiles covering typical configurations of materials exposed in cuttings were developed in advance of fieldwork on the assumption that they each represent a different design problem. The profiles are reproduced by BRAND (1982) and are discussed in BRAND & HUDSON (1982).

DECOMPOSITION GRADE STATISTICS

Grades were assigned to materials according to a group of indices rather than a single definitive property so it is revealing to compare the grades statistically to see how the indices varied within each grade as identified for the CHASE study. The range of index values from selected tests for each decomposition grade and colluvium fine fraction are presented in Fig. 1.

The three 'strength' tests were of varying usefulness in distinguishing between decomposition grades. The 'N' Schmidt hammer was particularly useful for this purpose, although a distinction cannot be made between the weaker materials (grades V, VI and colluvium fine fraction). The results from the field test strength estimate show a clear trend of decreasing strength with increasing degree of weathering but the overlap between grades is generally too great for classification purposes. The hard penetrometer test can be used

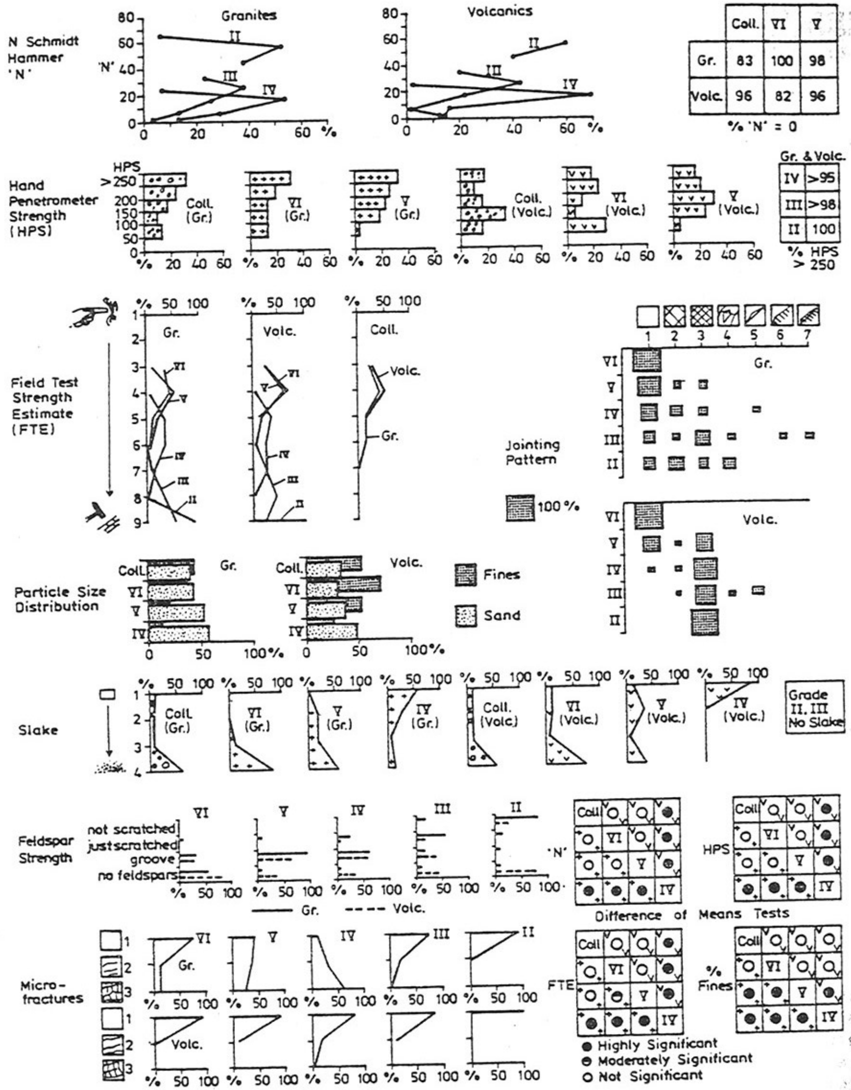

Fig. 1 - Material properties versus decomposition grade

to define the boundary between grades IV and V fairly successfully, but its main use is for quantifying the strength of weak materials.

The practical value of the slake test in helping to define the boundary between grades IV and V materials is shown by the fact that over 90% of granite samples and 85% of volcanics showed some signs of slaking (classes 2 to 4) in grade V, with corresponding figures of about 40% and 10% in grade IV. Grade VI material and colluvium fine fraction generally disintegrate in water.

The feldspar strength test results show considerably more overlap between grades than the various strength and slake tests, although a trend of decreasing resistance to scratching with increasing weathering grade is evident for grades II to V inclusive in both rock types. It is interesting to note that feldspars were not recognised by the field teams in up to 10% of grades II and III granite - a rock which, by definition, contains a high percentage of feldspars. Similarly, feldspars were not recognised in almost twice as many grade II volcanics as in grade V. This reflects the need for a degree of mineralogical knowledge for this test. As the rock decomposes, the feldspars become easier to recognise due to their weakness relative to quartz and their tendency to change to a white colour with the development of kaolin.

Microfracturing is much more prevalent in granite than in the volcanics. Significant extensive microfracturing is restricted to grade IV and, to a lesser extent, grade V granite. In preparing Fig. 1, the data from coarse and fine fractions were examined separately for each decomposition grade and were only combined when it was clear that there was no significant difference between the results obtained from these fractions. However, it was found that in the case of microfracturing in grade IV granite, only 23% of the coarse fraction was extensively microfractured compared with 52% of the fine fraction. This implies that the engineering behaviour of grade IV granite may depend on whether it forms the predominant matrix material or is contained as corestones within a weaker matrix. This was also reflected by the corresponding field strength estimate and slake test results which showed a tendency for increasing resistance to slaking and higher strengths in the coarse fraction.

The jointing pattern data confirm the common observation that joint spacing is generally much closer in the volcanic rocks of Hong Kong than in the granitic rocks. It should be noted that there is an inverse relationship between degree of jointing and microfracturing as shown in Fig. 1 for grade IV granite and volcanics. The differences in jointing can be attributed to the different tectonic histories of the two rock types, the volcanics having been intruded by the granite. The differences in degree of microfracturing may reflect the distinct grain sizes of the rock types but more probably is a result of elastic rebound being accommodated by the closer jointing in the volcanic rocks and not in the granite. This is supported by the observation that for grade IV granite, microfracturing is more extensive in the fine fraction (closer to the free surface) than in the corestones. It is also significant that very few cases of joints defining potential failure modes were recorded in grade IV and V granite and none in the volcanics. This casts some doubt on the importance often attached to relict jointing in controlling slope stability in highly to completely decomposed material. Similarly it can be concluded that joints 'heal' in rocks as they become more highly decomposed.

The particle-size distribution results confirm the direct link between fines content and decomposition grade in the advanced stages of weathering in both rock types. As a corollary, the percentage sand generally decreases as weathering proceeds but the differences between grades are less marked than for fines content. The higher percentage of fines in volcanic materials compared with the granite reflects the finer-grained original texture of the volcanic rock.

The results of the infiltration tests are not presented here but generally show the volcanic materials to be much less permeable than the granite. The most interesting feature, however, is the absence of significant differences between decomposition grades for each rock type. It can be concluded that infiltration rate is a complex parameter which cannot be directly related to the degree of weathering alone.

The significance of some of the index tests for distinguishing between decomposition grades has been assessed statistically using the analysis of variance technique and the results are summarized in the small matrices in Fig. 1. Within each matrix the distinction between all combinations of grades IV to VI and colluvium in each rock type has been classified into highly significant, moderately significant or not significant. For example, in both granite and volcanics, the 'N' values for grades IV and V are significantly different but there is no significant difference between grades V and VI.

AN EXAMPLE OF THE DIRECT APPLICATION OF INDEX TEST RESULTS

Redefinition of Slopes

The aim of the CHASE study was to establish the distinguishing characteristics between failed and stable slopes by empirical means and this has been discussed elsewhere (BRAND & HUDSON, 1982). Preliminary analysis of the accumulated data showed that a distinction could not be made on the basis of simple relationships such as slope height versus angle and that other factors had to be taken into account. It was recognised that each stable slope consisting of more than one layer could be considered as a number of separate cases - a one-layer slope, a two-layer slope and so on, each comprising a different proportion of the original slope and each with different geotechnical characteristics. This is illustrated in Fig. 2. Similarly, in cases where the failure scar did not extend over the full

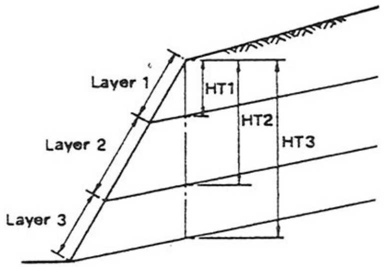

Fig. 2 - Redefinition of a stable slope into three distinct cases. (Layer boundaries assumed inclined at half natural slope angle).

height of the original slope, a failed slope could be redefined with the foot of the failure scar marking the toe of the new slope and the 'strength' dependent upon the nature of the layers cut by the failure scar. It was decided to attempt to characterise each new slope by a 'strength' factor.

Material Strength

To define the strengths of individual layers it was first necessary to determine the strengths of materials as indicated by field tests and secondly to quantify the effect on strength of the included coarse fraction.

The most useful field index tests for deriving a shear strength index for materials are the hand penetrometer strength (HPS) and 'N' Schmidt hammer rebound value (N). As can be seen from Fig. 1, HPS values are generally obtained for weak materials with N = 0. Above the useful range of HPS the N values can be used.

To develop a shear strength index, reference was made to a collection of point load-tested samples held by the GCO. These samples are marked with their approximate unconfined compressive strengths. From experience in the identification of weathering grades, a tentative correlation was made between N and compressive strength. This correlation was supplemented by the range of field test strength estimate results for each decomposition grade as shown in Fig. 1. The field tests used in this study are very similar to those recommended by the Working Party on the Description of Rock Masses (ANON 1977) which also gives a correlation with unconfined compressive strength. Combining this information and assuming that shear strength equals half the unconfined compressive strength, Fig. 3 has been compiled showing the 'shear strength' of decomposition grades as defined by N. Assuming that where N = 0 the shear strength index (S) can be represented by the cohesion value obtained from the hand penetrometer strength test, the following equation can be used to represent the shear strength of a material in kN/m^2 :-

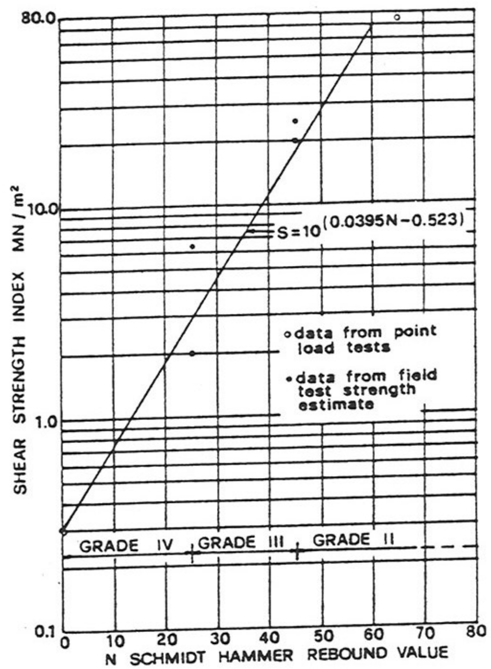

Fig. 3 - Shear strength index (S) versus N value

$$S = HPS - 300 + 1000 \times 10^{(0.0395N - 0.523)} \quad (1)$$

Although a number of greatly simplified assumptions have been made to derive this equation, the authors consider that the variation in S reflects a true variation in material strength.

Layer Strength

In a recent geotechnical report to the Hong Kong Government (OVE ARUP & PARTNERS, 1981) it was noted that the *in situ* strength of bouldery colluvium is higher than the laboratory-measured shear strength of the colluvial matrix. This conclusion was based on a comparison between strength values derived from the back analysis of failed and stable slopes (assuming a safety factor of 1.0) and laboratory test results. Careful appraisal of their results suggests that the *in situ* strength of colluvium with a boulder content between 75% and 100% is at least 30% higher than the strength of the matrix. There is only a small increase in strength for a boulder content of 25% to 50%. This confirms the findings of HOLTZ (1960) who showed that for a clayey soil there is no increase in strength until the gravel content exceeds 35% and for a sandy gravel there is no increase in strength until the gravel content exceeds 20%. The theoretical importance of a coarse fraction content of 30% in marking a change in shear behaviour has already been noted in the context of delineation of layers.

To take account of this increase in strength, the following equation was used by the authors :-

$$\text{Layer Strength (LS)} = S(1 + \frac{3}{700} \times (C-30)) \qquad (2)$$

where S is the shear strength index of the fine fraction, and C is the coarse fraction percentage.

Slope Strength

The strength factor for a slope (AVSTRENGTH) was calculated by averaging the strengths of the layers proportionally over the height of the redefined slope.

Figure 4 is a plot of redefined slope height versus slope angle for stable slopes and slopes with face failures which were not joint controlled. Face failures were distinguished from head failures according to their locations within slope profiles, as discussed by BRAND & HUDSON (1982).

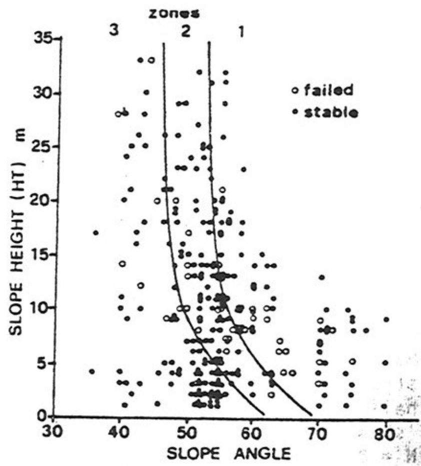

Fig. 4 - Height versus angle. Redefined slopes

In Figure 5, AVSTRENGTH has been incorporated for each slope as a divisor with slope angle. This new function gives a high number for a high-angle slope in weak material and *vice versa*.

For comparison, the data in Figs. 4 and 5 have been separated into three zones containing equal numbers of slope cases. The degree of separation is indicated by the ratio of failed to stable slopes in each zone (F/S) and these ratios are shown in Table III.

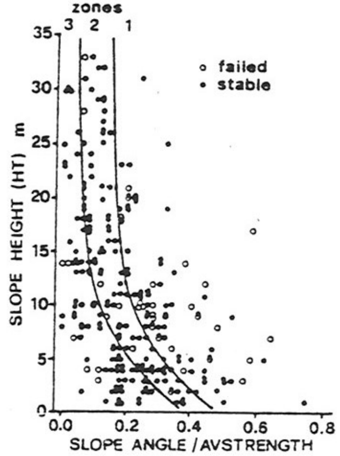

Fig. 5 - Height versus angle/ AVSTRENGTH

TABLE III
FAILED : STABLE SLOPE RATIOS

Figure	F/S			
	Zone 1	Zone 2	Zone 3	All Data
Height vs. Slope Angle	0.36	0.22	0.1	0.22
Height vs. Slope Angle/ AVSTRENGTH	0.5	0.13	0.12	0.23

It is evident from this table that a higher degree of overall separation between failed and stable slopes results from incorporating a 'strength' factor as obtained directly from field index tests.

This is only one example of how index tests can be used for quantitative purposes. For the CHASE study many other factors, including other material indices, were incorporated, and other statistical methods were used before arriving at the best separation between failed and stable slopes. This is discussed by BRAND & HUDSON (1982).

CONCLUSIONS

A systematic method for the description of weathered materials based on simple field tests and quantitative measurements and estimates has been presented here. The recommended methods have been extensively field-tested and have proved workable for geologists and non-geologists alike.

It is considered that the criteria given here for classifying weathered materials into decomposition grades allow a much more objective assessment than has previously been possible and therefore increases the quality of the classification scheme. The ability to recognise a decomposition grade does not, however, replace the need for recording basic data.

The concept of weathering zones has not been found useful for site description in this study. For engineering purposes, emphasis should instead be placed on the complete description of distinct layers or zones no matter where they occur within the weathering profile. Similarly, by describing materials fully using index tests, the origin of material becomes less important for characterising engineering properties. However, such information is of course still necessary for interpreting geological structure.

The example given demonstrating the quantitative manipulation of index test results is only one of many possible applications. Perhaps the most important application will result from the correlation of field test indices with laboratory test results as normally carried out for conventional analysis.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the major contributions to the CHASE study made by Messrs R. Hudson and R. Lumsdaine who supplied the organisational and computing skills respectively. Much of the field work was carried out by civil engineering graduates and students, and their dedicated efforts in often difficult circumstances is gratefully acknowledged. In particular, the work of Hammer Chui, Raymond Kong and Petrus Yung deserves special mention. This paper is published by permission of the Director of Engineering Development of the Hong Kong Government.

REFERENCES

ANON (1970), "The Logging of Rock Cores for Engineering Purposes", Quarterly Journal of Engineering Geology, Vol. 3, pp 1-24.

ANON (1972), "The Preparation of Maps and Plans in Terms of Engineering Geology", Quarterly Journal of Engineering Geology, Vol. 5, pp 295-382.

ANON (1977), "The Description of Rock Masses for Engineering Purposes", Quarterly Journal of Engineering Geology, Vol. 10, pp 355-388.

ANON (1979), "Classification of Rocks and Soils for Engineering Geological Mapping. Part 1: Rock and Soil Materials", Bulletin of the International of Engineering Geology, No. 19, pp 364-371.

BAYNES, F.J. and DEARMAN, W.R. (1978), "The Relationship between the Microfabric and the Engineering Properties of Weathered Granite", Bulletin of the International Association of Engineering Geology, No. 18, pp 191-197.

BERRY, P., MARTINETTI, S., F., RIBACCHI, R. and SCIOTTI, M. (1978), "Cataclasis and Alteration of a Granitic Rock and Their Influence on the Geomechanical Characteristics", Proceedings of 3rd International Congress of the International Association of Engineering Geology, Madrid, Session II, Vol. 1, pp 123-138.

BRAND, E.W. (1982), "Analysis and Design in Residual Soils", Proceedings of the ASCE Geotechnical Engineering Division Speciality Conference on Engineering and Construction in Tropical and Residual Soils, Honolulu, pp 89-143.

BRAND, E.W. and HUDSON, R.R. (1982), "CHASE: An Empirical Approach to the Design of Cut Slopes in Hong Kong Soils", Proceedings of the 7th Southeast Asian Geotechnical Conference, Hong Kong (in press).

BRITISH STANDARDS INSTITUTION (1981), "Code of Practice for Site Investigations", B.S. 5930 : 1981.

DEARMAN, W.R. (1974), "Weathering Classification in the Characterisation of Rock for Engineering Purposes in British Practice", Bulletin of the International Association of Engineering Geology, Vol. 9, pp 33-42.

DEERE, D.U. and PATTON, F.D. (1971), "Slope Stability in Residual Soils", Proceedings of the 4th Pan American Conference on Soil Mechanics and Foundation Engineering, Puerto Rico, Vol. 1, pp 87-170.

DE MELLO, V.F.B. (1972), "Thoughts on Soil Engineering Applicable to Residual Soils", Proceeding of the 3rd Southeast Asian Conference on Soil Engineering, Hong Kong, pp 5-34.

FOOKES, P.G. and HORSWILL, P. (1970), "Discussion on Engineering Grade Zones", Proceedings of Conference on In Situ Investigation in Soils and Rocks, London, pp 53-57.

GEOTECHNICAL CONTROL OFFICE (1979), Geotechnical Manual for Slopes, Government Press, Hong Kong, p 227.

HOEK, E. and BROWN, E.T. (1980), "Empirical Strength Criterion for Rock Masses", Journal of the Geotechnical Engineering Division, ASCE, Vol. 106, pp 1013-1035.

HOLTZ, W.G. (1960), "Effect of Gravel Particles on Friction Angle", Proceedings of the American Society of Civil Engineers Research Conference on Shear Strength of Cohesive Soils, Boulder, Colorado, pp 1000-1001.

INTERNATIONAL SOCIETY FOR ROCK MECHANICS (1978), "Suggested Methods for the Quantitative Description of Discontinuities in Rock Masses", International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, Vol. 15, pp 319-368.

INTERNATIONAL SOCIETY FOR ROCK MECHANICS (1981), "Basic Geotechnical Description of Rock Masses, International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, Vol. 18, pp 85-110.

IRFAN, T.Y. and DEARMAN W.R. (1978), "Engineering Classification and Index Properties of a Weathered Granite", Bulletin of the International Association of Engineering Geology, No. 17, pp 79-90.

LUMB, P. (1962), "The Properties of Decomposed Granite", Géotechnique, Vol. 12, pp 226-243.

LUMB, P. (1967), "The Residual Soils of Hong Kong", Geotechnique, Vol. 15, pp 180-194.

MOYE, D.G. (1955), "Engineering Geology for the Snowy Mountains Scheme", Journal of the Institution of Engineers, Australia, Vol. 27, pp 287-298.

MUNSELL (1975), Munsell Soil Colour Charts, Munsell Color, Baltimore, U.S.A.

NEWBERRY, J. (1971), "Engineering Geology in the Investigation and Construction of the Batang Padang Hydroelectric Scheme, Malaysia", Quarterly Journal of Engineering Geology, Vol. 3, pp 151-181.

NICHOLS, T.C. Jr. (1980), "Rebound, Its Nature and Effect on Engineering Works", Quarterly Journal of Engineering Geology, Vol. 13, pp 133-152.

OVE ARUP & PARTNERS, HONG KONG LTD. (1981), "Case Histories Subject Report, Glenealy, Seymour and Central Areas", Midlevels Study, Report to Hong Kong Government, Vol. 1 (text), pp 84-85.

PITEAU, D.R. (1970), "Geological Factors Significant to the Stability of Slopes Cut in Rock", in Planning Open Pit Mines (Ed. P.W.J. Van Rensburg), South African Institute of Mining and Metallurgy, Johannesburg, pp 33-53.

RUXTON, B.P. and BERRY, L. (1957), "Weathering of Granite and Associated Erosional Features in Hong Kong", Bulletin of the Geological Society of America, Vol. 68, pp 1263-1291.

TERZHAGI, K. and PECK, R.B. (1967), Soil Mechanics in Engineering Practice, John Wiley & Sons, Inc., New York, p 729.