02 Jun 1988, 10:30 am - 3:00 pm

Slope Stability Evaluation for an Existing Steep Cut in Weathered Volcanics, Hong Kong

J. K. P. Kwong
Dames & Moore, Honolulu, Hawaii

L. J. Endicott
Dames & Moore, Hong Kong

A. C. Lumsden
University of Leeds, England

Proceedings: Second International Conference on Case Histories in Geotechnical Engineering, June 1-5, 1988, St. Louis, Mo., Paper No. 2.08

Slope Stability Evaluation for an Existing Steep Cut in Weathered Volcanics, Hong Kong

J.K.P. Kwong
Presently Dames & Moore, Honolulu, Hawaii

L.J. Endicott
Dames & Moore, Hong Kong

A.C. Lumsden
University of Leeds, England

SYNOPSIS : This case study concerns an investigation of a major existing soil slope. It is a 60m (197 ft) high cutting slope, at 40 degrees to 60 degrees to the horizontal, exhibiting a considerably greater degree of stability than was obtained by a series of geotechnical investigations and analyses.

The common practice of correlation between widely spaced borings is shown to be inappropriate at this site because of the highly variable ground conditions. Rather, the comprehensive geological comprehensive engineering investigation carried out has enabled a detailed appreciation of the distribution and nature of weathered materials at the site. Transitional materials with soil-like appearance and weak rock properties have been identified. Based on this information, slope stability evaluation was carried out with more realistic results and with greater confidence.

INTRODUCTION

Due to the steepness of the hilly terrain and intensive development of Hong Kong there are many large steep slopes in close proximity to occupied high rise buildings. Analysis of these slopes is important because of the severe consequences if they were to fail. Investigation is often costly due to difficult access and size of the slopes involved. Such has been the demand for development that even the steep slopes themselves may be considered as development sites. These circumstances are further complicated when an investigation obtains factors of safety of below unity for commonly occuring conditions and with no signs of imminent collapse.

PREVIOUS EXPLORATORY PROGRAMS

Considerable borehole data for the site existed prior to this study due to the many attempts by successive owners to obtain permission to develop the upper part of the site. In addition, in 1978 an investigation of the slope was carried out following which horizontal drains were installed in the lower portion of the slope (Tong and Maher 1975), (Figure 1). The next investigation primarily consisted of 30 borings and the hand excavation of a caisson shaft which permitted the installation of a series of tensiometers which were used to measure pore water suction in the ground at various depths (Sweeney 1982). Research into the effects of unsaturation on shear strength was carried out (Fredland 1981) in order to reconcile the observed stability of the slope with the low factors of safety obtained previously.

PRELIMINARY EVALUATION

The unusually large number of borings already drilled prior to this study facilitated to the early development of a geological model of the complex subsurface conditions. From the interpretation of aerial photographs, geological site surface mapping, and review of existing borehole data and ground water level monitoring, three major zones of deep weathering were considered to extend across this area (Figure 2). Correlation of field mapping and borehole data suggested that these zones of deeper weathering were probably shear or fracture zones in the rock mass.

The deeper zones of weathering also exhibited permanent ground water. Horizontal drains installed along the deeper zones of weathering, and the drains which intercept these zones at depth were found to yield a permanent flow of

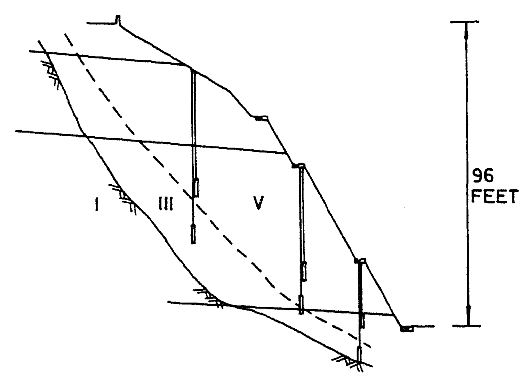

Fig. 1 Lower Slope Section Showing Horizontal Drains and Piezometers

Fig. 2 Site Plan Showing Zones of Deep Weathering

ground water during dry seasons. The presence of these deeper zones of weathering and fracturing and their inferred attitudes indicates that they serve as preferred paths where ground water from both regional and local sources could be concentrated. In areas associated with these zones, a seasonal rise of ground water is evident from both piezometer monitoring and from seepage stains beneath horizontal drains.

Elsewhere on site there is a general lack of ground water both at the relatively higher soil to rock interface and within the bedrock.

Samples remaining from some of the previous borings were re-logged in greater detail, and it was suspected that a transitional zone, not recognised previously, exists between the grade V and the grade IV weathered volcanic rock. Classification of the grades of weathering is given in Table 1.

Based on the findings of this preliminary evaluation, geological factors relevant to slope stability evaluation at the site include:-

a. The highly variable rockhead and weathered profile, which may be the result of differential weathering along shear zones and granite/volcanics contact areas.

b. The presence of a significantly thick but variable transitional zone of weak rock material at the soil to rock interface.

c. The weak rock material is sensitive to sampling disturbance.

d. The occurrence of ground water, which was found to be associated with geological structures.

TABLE 1 : Weathering Classification

Grade	Degree of weathering	Typical Diagnostic Features
VI	Residual	Soil, original rock fabric destroyed.
V	Completely Weathered	Soil, discolouration, original rock fabric is mainly preserved.
IV-V	Transition Material	Soil-like to rock-like, highly variable, rock fabric preserved.
IV	Highly Weathered	Rock weathered, discoloured throughout, variable, weak rock, alteration of primary minerals.
III	Moderately	Partially weathered, discoloured, joints stained to altered, some alteration of primary minerals.
II	Slightly Weathered	Rock slightly discoloured, particularly adjacent to discontinuity.
I	Fresh	No stains along joints, no alteration of minerals.

A detailed exploratory program was planned to test the geological model, to better interpret the ground conditions, and to provide more realistic geotechnical engineering parameters.

EXPLORATION FIELDWORK

Additional fieldwork was carried out for this study. 12 vertical and 4 horizontal drillholes were each selected for a specific purpose such that the geological features of the site can be defined. During the course of the field exploration, the locations of some of the later holes and test pits were revised as a result of the information obtained from the first few holes and test pits. Core samples of soil, transitional material and rock were obtained using a Mazier retractable triple tube core barrel. Block samples of weathered rocks were collected from trial pits and exposed areas on the existing cut slope. Grades of weathering were classified by visual examination and a pocket penetrometer modified for testing strong materials was used to provide a quantitative index strengths of materials which had undergone different degrees of weathering (Figure 3), (Kwong et al., 1984).

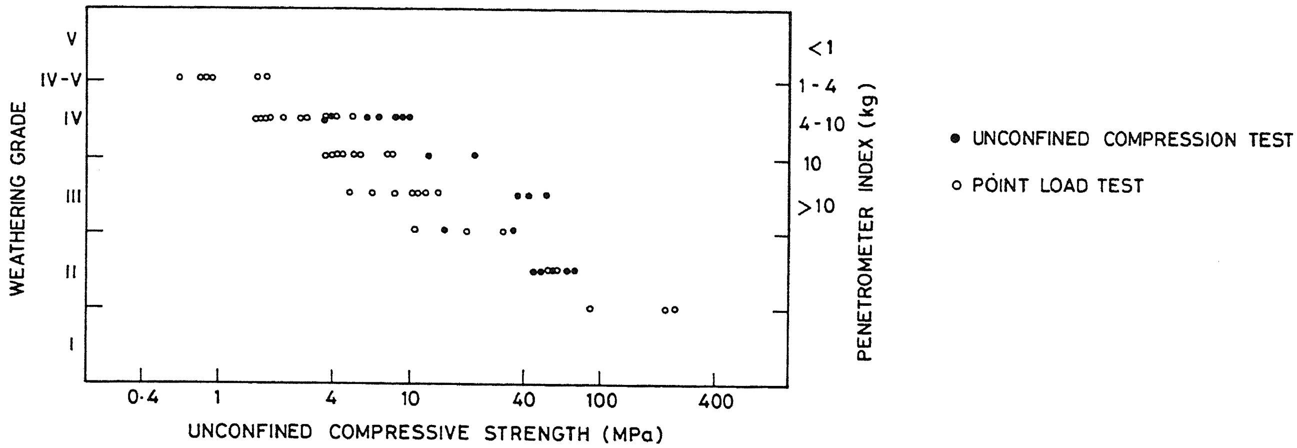

Fig. 3 Index Strength Test Results (After Kwong 1985)

DETAILED EVALUATIONS

The volcanic and granite rock mass at depth is generally grade III. Except along major stream courses, to either side of the site, a weathering mantle capped by thin colluvium covers the study area. In most areas, where a soil to rock interface exists, the rock is grade III to IV. The soil to rock interface is a transitional zone comprised of grade IV to V material. The transitional materials usually have high SPT "N" values (N=80 to >200) and when soaked in water, only the disturbed part of the sample disintegrates. A layer of grade V volcanic soil generally overlies this transitional zone (Figure 4).

The thickness of the materials in the weathering profile varies across the study area. The transitional zone is thickest in the area of deep weathering associated with closely spaced fracturing and shearing of the rock mass.

The zones of the slope classified previously as soil were found to consist primarily of grade IV, transitional, and grade V weathered volcanic rock. The deeper weathering profile is believed to be controlled by a very complex geological condition. Detailed logging of recovered rock cores and petrographic examination of thin sections prepared from rock samples indicted that the welded tuff was

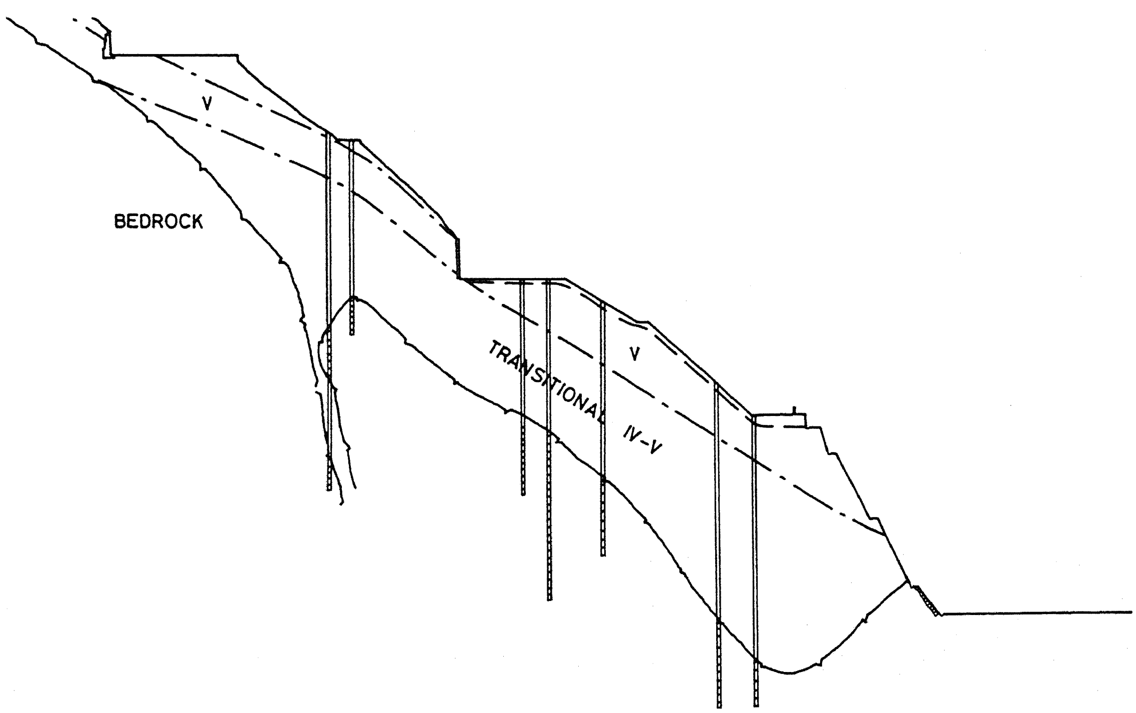

Fig. 4 Cross Section of Slope

affected by the younger granite intrusion, and was tectonically fractured. Alteration to the otherwise unweathered volcanic rock is believed to be mainly due to chemical weathering, as the degree of weathering appears to be associated with openings or fractures in the parent material, and in general, the degree of weathering also decreases with depth.

Differentiation between grade V, transitional and grade IV materials was further studied with the use of a scanning electron microscope for purposes of examining the microfabric. In parallel the mineral content of specimens of each material was determined by the use of X-ray diffraction techniques. The transitional material was classified as a soil-like but weak rock which still retains a skeletal framework of physical and chemical bonds between partially weathered feldspars and quartz crystals. These bonds contribute to a cohesion of the material and prevent slaking of a soaked sample. However the bonds are weak and can be broken by sampling disturbance (Kwong 1985).

For grade V materials, significantly high values for cohesion have not been found; although there is evidence of strength reduction around the periphery of carefully taken Mazier samples (Kwong, 1985).

The strength parameters for grade V, transitional, and grade IV materials were obtained by performing consolidated drained triaxial tests on Mazier samples (Figure 5), Table 2. Point load strength tests and unconfined compression tests were carried out using NX size cores, (Figure 3).

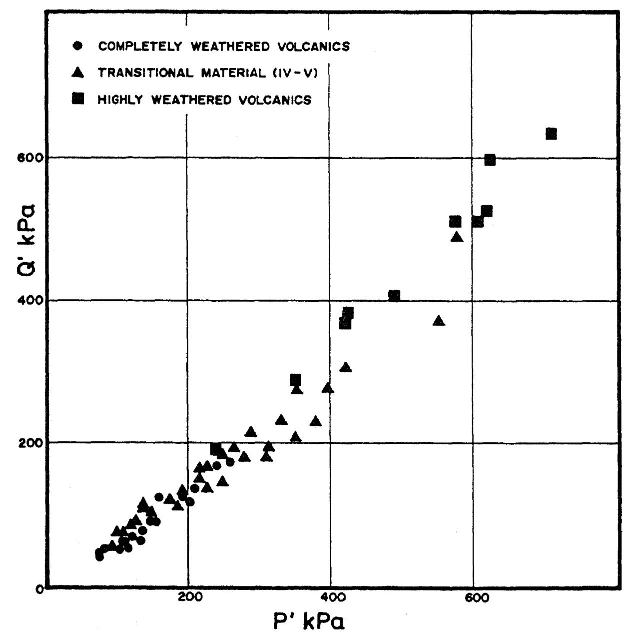

Fig. 5 Triaxial Strength Test Results

Slope stability calculations, carried out as part of this investigation, obtained factors of safety close to 1.4 for deep seated failure surfaces under designed conditions relating to 10 year return period rainstorms. Shallow slip surfaces of the steeper areas, above the predicted water table, obtained factors of safety of as low as 1.0 under saturated (no suction) conditions. Whereas slope stability calculations carried out previously obtained factors of safety as low as 0.55 initially for deep seated failures, rising to above 1.0 on the basis of selective use of triaxial test strength data and allowing for an increase of strength with depth.

TABLE 2 : Strength Parameters

Type	c' (kPa)	ø' (deg.)
Grade V	9	37
Transitional	18	39
Grade IV	34	42.5

CONCLUSIONS

This case study shows that vertical and lateral changes in the degree of weathering and in the soil to rock interface can be difficult to interpolate between vertical borings. An understanding of the conditions confirmed by appropriate field work is essential.

Recognition of transitional materials, between grade IV and V, with a soil-like appearance and a weak rock microfabric is important. Its strength can contribute significantly to the stability of slopes. Failure to recognise this material can lead to unrealistically low assessment of stability.

The transitional material is sensitive to disturbance. Very careful sampling and testing is required.

REFERENCES

Fredlund, D.G., 1981. The shear strength of unsaturated soils and its relationship to slope stability problems in Hong Kong. H.K. Engineer, Vol. 9, No. 4, pp. 37-45.

Hencher, S, 1987. Private communication.

Kwong, J.K.P., 1985. Effects of geological and environmental factors on the engineering properties of weathered igneous rocks in Hong Kong. Ph. D. Thesis, University of Leeds.

Kwong, J.K.P., Lumsden, A.C., Endicott, L.J., and Smalley, I.J., 1984. Engineering Geology and Slopes Stability Problems in Chemically Weathered Terrain, Proc. 27th Int. Geol. Conf., 1984, Moscow.

Sweeney, D.J., 1982. Some in-situ soil suction measurements in Hong Kong's residual soil slopes. Proc. 7th South East Asian Geotechnical Conference, Nov. 1982, Hong Kong, Vol. 1, pp. 91-106.

Tong. P.Y.L. and Maher, R.O., 1975. Horizontal drains as a slope stabilising measure. Hong Kong Engineer, Vol. 3, No. 1, pp. 15-27.