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A Survey of Road Cuttings in Western Malaysia

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ABSTRACT

The heterogeneity of soils, rocks and strata in cuttings frequently makes realistic analysis of the stability of cut slopes difficult. This is particularly true when cuts are made in weathered sedimentary rocks of an argillaceous nature. In the tropics stability predictions are further complicated by the twin factors of surface erosion and the softening of some newly exposed rocks.

Analytical design in these circumstances is often impossible and rarely economically justifiable; empirical design methods based on the systematic collection of slope performance data provide a logical alternative.

This paper gives details of a recent survey of a large number of cut slopes in western Malaysia to provide data on the long-term stability of slopes. Preliminary analysis of these data showed that the materials composing the slopes could be classified into seven geological types; recommendations are made for the slope angles appropriate to each of these.

INTRODUCTION

The stability of embankments has received much attention from research workers over the years. Today the stability of an embankment can be predicted with sufficient accuracy in the majority of cases from slip circle analyses which consider the pore water pressures in the embankment and use shear strength parameters obtained under testing conditions approximating those in the actual structure (SKEMPTON 1948, 1954, 1964; BISHOP and MORGENSTERN, 1960). The precision attained in developing and applying analytical techniques to embankments is largely due to the fact that embankment slopes are amenable to rational analysis and to the stimulus provided by the construction of large numbers of earth fill dams.

The stability of natural and excavated soil slopes can also be successfully analysed provided there is full knowledge of the conditions and variations within the soil mass. With increasing variation and multiplication of soil layers and types the mathematical treatment becomes extremely complicated and time consuming. In practice, too, it is often difficult to obtain sufficient information on sub-surface soil conditions and indeed in many cases the expense of a thorough soil survey could not be justified. Additionally there are those slopes composed partially of decomposing rock as well as soil. The treatment of these, falling as it does between the realms of soil mechanics and rock mechanics, is not yet amenable to analysis; they present a special problem which, though defined by several research workers (HIGHWAY RESEARCH BOARD, 1963) still needs investigation.

An empirical approach to cut slope stability therefore has much to recommend it in road building where several different slope treatments may be required within the space of a mile. In these circumstances slopes are excavated to some angle based on previous experience.

This empirical approach, based on the systematic collection and appraisal of slope performance, is justified when the cost of any remedial treatment is less than the expense of the thorough soil exploration needed for a rigorous stability analysis, assuming equal risk of slipping in both cases. In most rural situations in developing countries additional land to accommodate flatter slopes can be easily obtained but it is more economical to use steeper slopes involving some risk of slipping.

This paper describes a survey undertaken during the past two years of a large number of slopes of cuttings in western Malaysia. Preliminary analysis of the data collected has been made and has enabled a simple classification of cutting materials to be formulated and general recommendations to be made for cut slope design in that region. Whilst the conclusions drawn relate specifically to western Malaysia they would be equally applicable in other regions with similar geology and climate.

STABILITY PROBLEMS IN TROPICAL ENVIRONMENTS

There are two factors affecting slope stability in the tropics that are not present to the same extent in temperate climates. These are (i) the rate of softening of weathered rock on exposure to the tropical climate, and (ii) the rate of surface erosion. Both of these are extremely difficult to predict quantitatively.

Water either moving or static is the prime cause of both mechanisms. Erosion and rock softening are complementary processes, the former frequently providing the means by which the latter develops. Thus, if the surface of a slope is protected against erosion, softening of the underlying material is greatly retarded. In cuttings both effects are important, but in embankments the main problem is generally surface erosion as embankments tend to be relatively dense and homogeneous internally and are unlikely to include water bearing strata.

In endeavouring to predict the degree of softening and erosion in a particular tropical situation the engineer must rely largely on past experience and observation. The conclusions drawn from this survey of the present condition of a large number of slopes in cuttings of various ages take the aggregated effects of both these factors into account.

THE SCOPE OF THE SURVEY

The survey covered over four hundred cut slopes of various ages which have been excavated in the course of establishing the present main road system in western Malaysia. The age ranges up to about 50 years. Only cuttings with a vertical height greater than 25 ft at their highest point were surveyed. Cut faces less than 25 ft high, although numerous, do not present problems since in nearly all the soils and rocks encountered in western Malaysia they remain stable when cut nearly vertically. The few that do slip absorb only a minor maintenance effort.

It is estimated that 95 per cent of all the major cutting slopes on the principal road network were surveyed. The roads included in the survey are indicated on Fig. 1. In addition a small number of the larger cut slopes on the railway system were also surveyed.

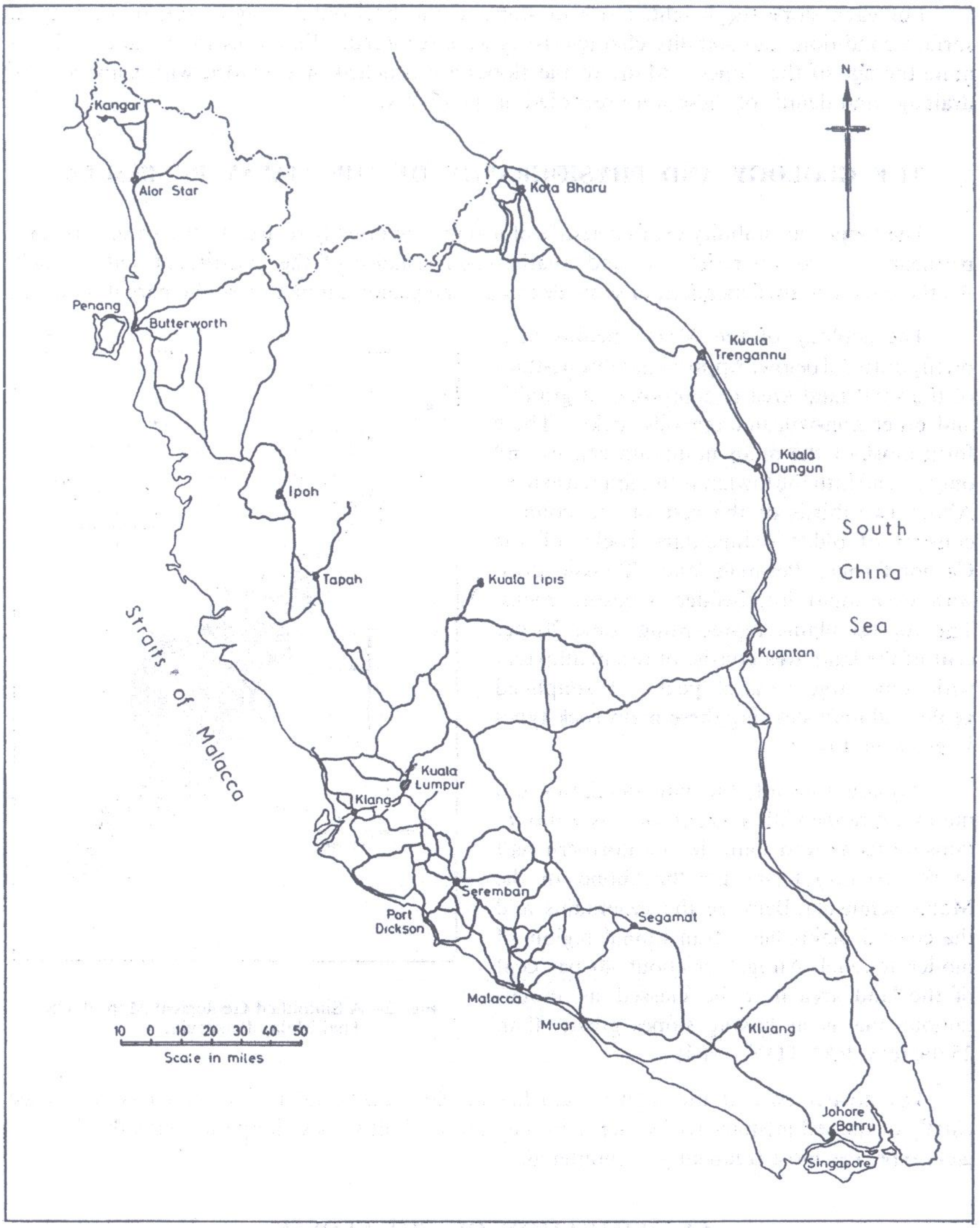

Fig. 1—The Roads Along Which Major Cut Slopes Were Surveyed.

For each slope the height, angle of slope to the horizontal, length, soil or rock type, surface condition, and stability characteristics were recorded. Enquiries were made to determine the age of the slopes. Many of the slopes are benched or provided with some sort of drainage and details of these were recorded in the survey.

THE GEOLOGY AND PHYSIOGRAPHY OF THE MALAY PENINSULA

The long-term stability characteristics of a slope are directly related to the shear strength, permeability, erosion resistance, and weathering resistance of the constituent soil or rock. All these factors are dependant in some degree on the geological history of the parent material.

The geology of the Malay peninsula is briefly outlined below. Approximately one-third of the total land area is composed of granitic and other non-volcanic igneous rocks. These form most of the main mountain ranges and only extend into the lowlands to a limited extent. About two-thirds of the rest of the country consists of older sedimentary rocks of the Carboniferous, Permian and Triassic eras, with occasional interbedded volcanic rocks. The coastal plains representing some 20 per cent of the land area consist of recent alluvium with some large areas of peat. A simplified geological map showing these main rock types is given in Fig. 2.

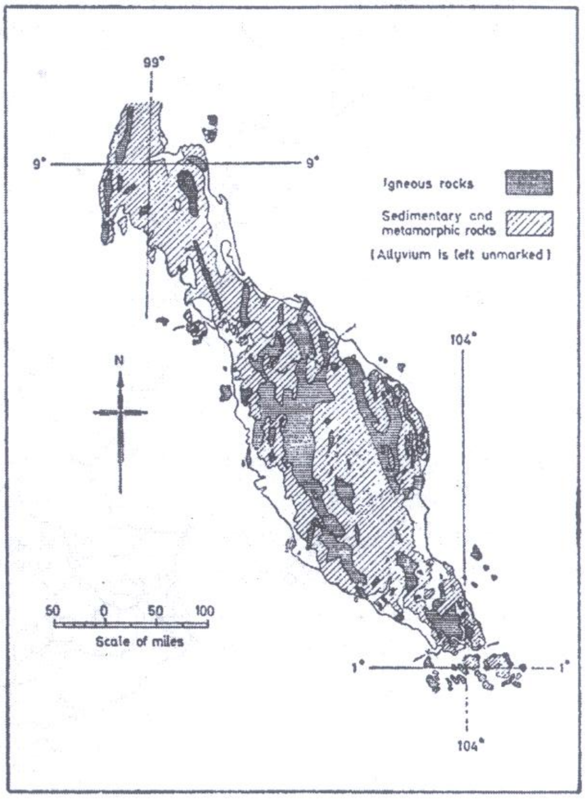

Fig. 2—A Simplified Geological Map of The Thai-Malay Peninsula.

Physiographically the main north to south mountain range with a group of lesser mountains on its eastern flank in the northern half of the country forms the 'backbone' of the Malay peninsula. Between the mountains and the coastal plains lies a transitional region of moderate relief. Altogether about 40 per cent of the land area may be classed as mountainous, that is, as having slopes greater than 25 degrees (PANTON, 1964).

The greater part of the road system lies in the transitional region which is composed chiefly of the sedimentary rocks; hence in the survey of cut slopes along the roads this lithological type was most frequently encountered.

CLASSIFICATION OF CUT SLOPES

On completion of the slopes survey it was apparent that from the stability point of view the cuts could be broadly classified by lithology into seven basic types. These types which can be readily recognised and identified are now described.

'Hard' Rock

All the unweathered igneous rock is included in this category; most commonly this is of the granite family. In some limited areas in the mountains hard unweathered shales and sandstones or their metamorphosed derivatives occur and these are also included in this 'hard' rock category. In the lowlands the sedimentaries are rarely found in the 'hard' state since weathering usually extends to a depth well below the floor of the deepest cutting.

'Hard' rock is defined as having the property of ringing when struck with a hammer, and requires explosives for its excavation.

Weathered Igneous Rock

Characteristically the igneous rocks, the majority of which are granites, weather to firm sandy clay soils often containing a fine gravel fraction in the form of residual quartz particles. The soil can range from a plastic sandy silty clay soil at the surface through sandy silt soils lower down to a gravelly silty sand soil adjacent to the unweathered rock. This sequency has been described in detail (LEDGERWOOD, 1963). In some occurrences the upper layers may be absent, leaving only the coarse-grained gravelly sand. Since this soil is inherently more stable than the fine-grained material it is necessary to distinguish two categories of these weathered igneous rocks.

Coarse-grained weathered igneous rock — defined as having 40 per cent or over retained on the B.S. No. 25 sieve. (= 0.6).

Fine-grained weathered igneous rock — defined as having less than 40 per cent retained on the B.S. No. 25 sieve. (= 0.6 mm).

Weathered Sedimentary Rocks

These rocks are the most frequently encountered in road cuttings in western Malaysia. They range from firm quartzite and sandstone to soft decomposed phyllite and shale. From the stability point of view it is useful to distinguish three main types.

'Firm' shales, schists and phyllites inter-bedded with sandstones and quartzites, the arenaceous beds comprising not less than 20 per cent by volume of the whole — The sandstones and quartzites are easy to distinguish from the argillaceous rocks by their grain size and texture. Normally in shallow cuts, up to 35 ft deep, these rocks can be excavated direct by scraper; in deeper cuts or where the arenaceous beds predominate rippers are likely to be required.

'Firm' shales, schists, and phyllites containing less than 20 per cent by volume of inter-bedded arenaceous sediments — The rock in this category ranges from multicolored weathered shales and phyllites in a series of thin beds to massive uniform deposits. This category is easier to excavate than the previous one in similar situations but may still require ripping in the deeper cuts.

'Soft' shales, schists, and phyllites — Materials in this category are the least stable of the sedimentary types. They are found in low hills some 40 to 50 ft high so that cuttings in the material are rarely more than 40 ft deep. When freshly exposed these rocks have the consistency of a firm clayey silt; on exposure they soon lose their cohesion and degenerate into a soft cohesionless silt. Characteristically they are pale grey or white in color, sometimes tinged pink or weak red. CLARE and NEWILL (1965) have indicated a connection between silt content and slope stability in such material and it appears that a silt content greater than about 60 per cent distinguishes the 'soft' sediments of this category from the 'firm' ones of the previous category. Grading curves of material from three weathered shale cuts are shown in Fig. 3 and their silt contents are compared with their slope stability performance in Table 1. For comparison three residual granitic soils are also included.

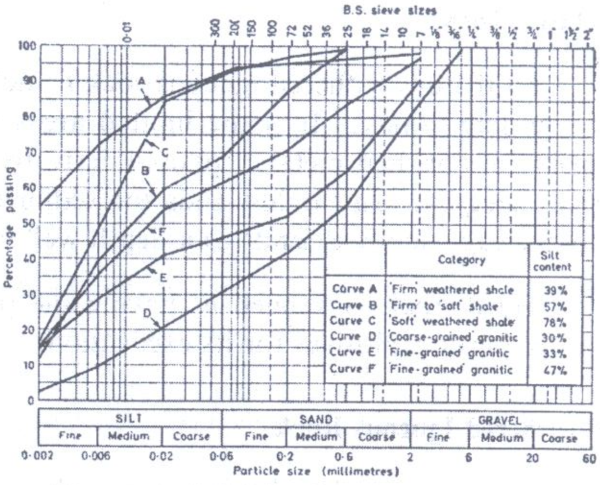

Fig. 3—Grading Curves of Samples from Shale and Granite Cuts.

Table 1
Stability Characteristics of Weathered Shales and Residual Soils.

Soil or 'rock' type	Silt content, per cent	Stability characteristics of a 45° slope, 35 ft high
'Firm' weathered shale	39	Stable
'Firm' to 'soft' shale (weathered)	57	Exhibits shallow slips
'Soft' weathered shale	78	Exhibits major slips
'Coarse-grained' granitic soil	30	Extremely stable
'Fine-grained' granitic soil	33	Stable
'Fine-grained' granitic soil	47	Exhibits shallow slips

Volcanic Rocks and Conglomerates

Rocks of volcanic origin occur in several distinct areas in the sedimentary rock regions. However, the occurrences are not extensive and there are few major road cuttings in them. Agglomerates and tuffs are the principal forms. In the unweathered state they constitute a separate category from the slope stability point of view in which it is convenient to group conglomerates also.

DISCUSSION

Survey Results

The results of the survey are summarized in Table 2 and general recommendations for stable slope angles are made.

Whilst the classification adopted is to some extent arbitrary in distinguishing the categories in the major geological groups and the many local factors affecting the stability of a particular slope are ignored, there are nevertheless distinct differences between the slope stability characteristics of the seven basic types defined. Local effects tend to be averaged out in the large number of cuts considered, and even such a basic factor as height does not affect the mean slope angle of a category. For instance, the weathered sedimentary slopes in the 'firm' and 'soft' categories, if grouped in two height ranges, below 35 ft and 35 ft and over in height, still have the same mean slope angle for both groups.

The relevance of calculating the mean slope angle for a category of slope, and then using this as a guide for future design, depends on the assumption that the slopes surveyed were originally too steep when constructed and subsequently at least a proportion of them either slipped or eroded to a shallower angle which provides permanent stability. The validity of this assumption is confirmed by the number of cuts surveyed that did exhibit past slipping but that appeared to have achieved stability when surveyed. The time factor is of course very relevant to the amount of both erosion and slipping, and though the mean slope angle shown in Table 2 includes cuts of all ages, in the design recommendations more weight has been given to the older slopes in each category.

Table 2
Summary of Survey Results.

Category of slope material		Number surveyed	Av. angle of slope degrees	Slopes with slips per cent	Slopes with erosion per cent	Slopes with 50% veg. cover per cent	Slopes with benching per cent	Slopes 10yr. old per cent	Recom-mended slop angle degrees
'Hard' rock		52	61	nil	nil	nil	50	92	60 - 70
Weathered igneous rock	'Coarse-grained', i.e. 40% or more retained on the B.S.25 seive (= 0.6)	55	53	30	28	9	64	95	50 - 60
	'Fine-grained', i.e. less than 40% retained on the B.S.25 seive (= 0.6mm)	56	47	15	26	46	57	50	40 - 45
Weathered sedimentary rock	Shales, schists, and phyllites with 20% or more interbedded sand-stone or quartzite	68	44	30	42	18	65	45	40 - 50
	Shales, schists, and phyllites with less than 20% interbedded sand-stone or quartzite	143	45	44	44	26	63	24	40 - 45
	'Soft' shales, schists and phyllites typically with 60% of silt	88	37	92	78	44	70	42	35 - 40
Volcanic rocks and conglomer-ates	Unweathered agglome-rates and tuffs, and conglomerates	18	52	39	34	28	50	90	45 - 55

Vegetation

The development of vegetation on a slope face greatly aids stability by reducing erosion and the penetration of surface water into the soil or rock mass. The softer materials in particular benefit from vegetative cover.

The soiling or seeding of slopes for roadworks is generally not economically feasible in developing countries and vegetation is left to establish itself if it can. In Malaysia the softer shales support growth most readily and can become completely covered in 4 or 5 years provided the surface is stable. However, in this time slipping probably will have occurred already in a slip-prone cut, so the vegetation when it comes will serve only to arrest further erosion.

Where full-turfing is employed it is estimated that it permits the soft weathered sedimentary slopes to be constructed up to 5° steeper than the equivalent unprotected slope, provided the turves are applied soon after construction. Spot-turfing though not so effective in arresting softening of the 'soft' sedimentaries, does help to prevent early erosion; it may permit some steepening in the firmer sedimentaries, fine-grained igneous and volcanic rock categories.

Surface Treatments

The stabilization of cut faces by spraying with bitumen emulsion or cut-back bitumen has been tried on several major cuts in Malaysia. It is most successful when applied to the stiffer granitic soils which are among the most stable in any case; its principal effect is to reduce to almost zero the small amount of erosion that would otherwise occur. Fig. 4 illustrates a good example of this treatment. A single application has a life of the order of 3 to 5 years. It is considered that if a seeded straw mulch was included in the treatment, as has been tried elsewhere (CHEPIL 1961), longer lasting benefits, due to the establishment of vegetation, would accrue.

The stabilization of the surface of slopes with cement or lime has been employed successfully in Malaysia. This is a relatively high cost treatment and it is not justified for general

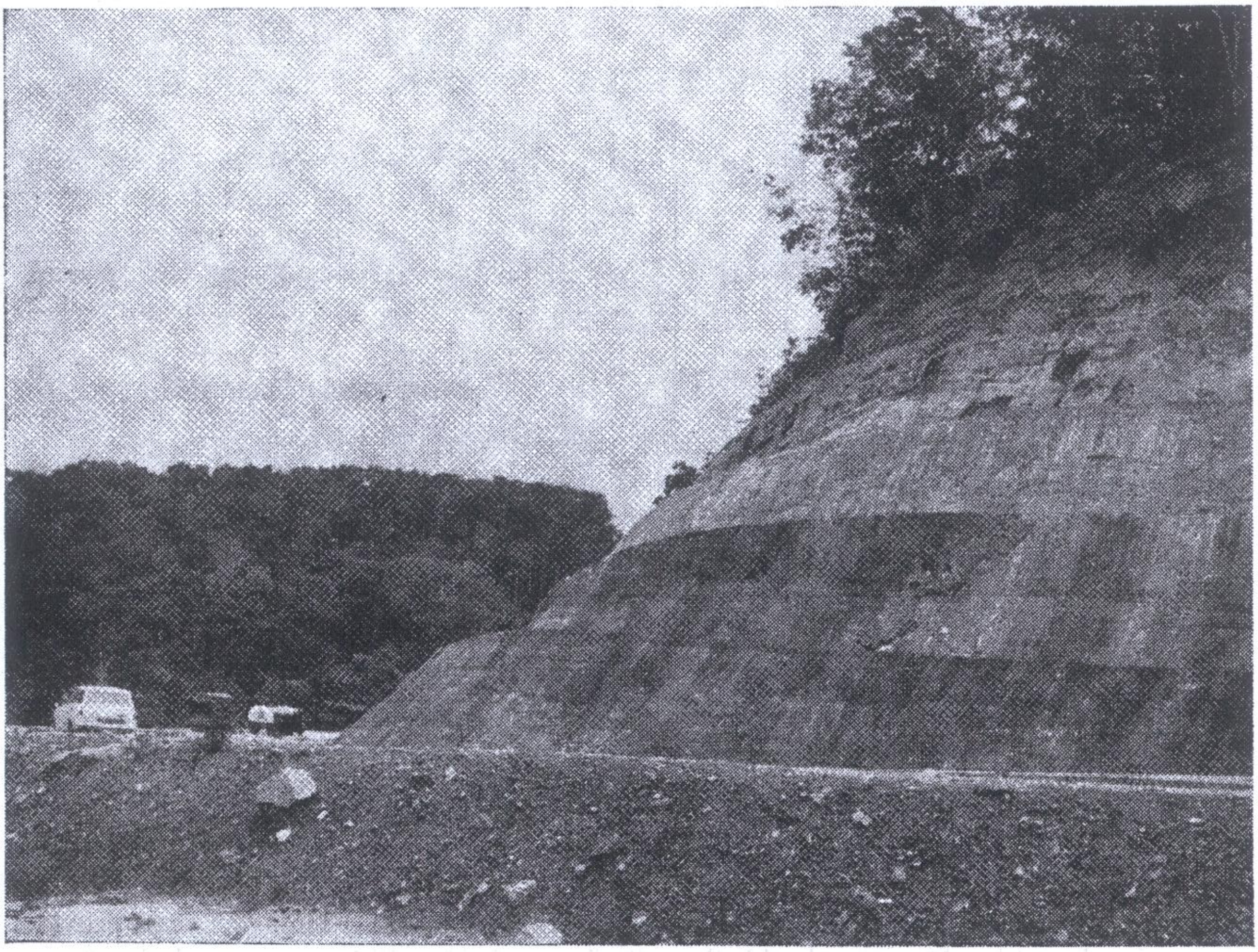

Fig. 4—A Cut in Residual Soil Granite Which Has Been Sprayed with Bitumen Emulsion.

application. It is most appropriate for the repair of local failures in an otherwise stable face in situations where appearance is important.

A natural phenomenon which affords some protection to cut slopes is the self-sealing action that occurs on the surface of some cuttings due to the deposition of iron oxide or organic matter. Iron-bearing water flowing over or through the face of the cutting evaporates and deposits iron oxide, which in time builds up into a hard crust. It appears that organic matter can also be deposited in much the same way. Table 3 shows the results of an analysis made on the surface skin and sub-surface of some cuttings in Malaysia (CLARE and NEWILL, 1965).

Table 3
Iron Oxide and Organic Content of Surface and Sub-surface Soils.

Road	Iron oxide content, per cent		Organic content, per cent	
	Surface	Sub-surface	Surface	Sub-surface
Kota Tinggi — Mersing	46.0	26.0	0.5	0.5
Raub — Kuala Lumpur	5.6	5.6	9.9	0.5
Kuala Lipis — Jerantut	2.2	0.2	3.5	0.1
Kuantan district	3.7	0.2	0.7	0.1
Tanah Merah — Jeli	9.3	7.4	7.1	0.5

This action can occur in any place where there is iron in the soil. It is most commonly found in cuttings in granitic soil, probably because this soil can maintain a firm smooth face for the many months necessary for the deposition to build up. The results from the first site show that iron oxide can accumulate at the surface without a corresponding increase in organic matter content: at the second site organic content has increased but not the iron content.

Drainage and Benching

A very important requirement of slope construction in wet tropical climates is the provision made for drainage. A well designed drainage system can greatly improve the stability of a slope; on the other hand a badly positioned drain can sometimes do more harm than good. Similarly if drains are not maintained and are allowed to clog up, the resulting overflow can cause more severe local erosion than if the drains had been omitted.

If a toe drain is placed too near to the foot of a slope it will be easily blocked up by every minor movement of material down the face. It is thus desirable to maintain a minimum of 8 ft between the drain and the toe of the slope. For the same reason wide shallow drains are preferable to narrow steep-sided ditches which are more easily clogged.

Cut-off drains at the top of cut slopes are better omitted except where there is direct evidence of appreciable flow of ground water over the top of the cut. Where the need for a cut-off drain is clearly established a built-up bund is preferable to a trench cut through the protective mat of vegetation or through the laterite crust that is often present.

Three-quarters of the cut slopes surveyed had been benched when they were constructed, though many of these benches has subsequently all but disappeared as a result of slips or erosion. The purpose of benches is:

(i) to trap local falls

(ii) to intercept water running down the face

and (iii) to reduce the effective surface area of sloping catchment presented to vertically falling rain by allowing the use of a series of steeper faces.

By implication benches lose much of their value if falls are not cleared regularly and the flat surface of each bench is not well protected against erosion. In practice both are neglected in most rural situations in developing countries. Where maintenance is unlikely to be carried out regularly benches are best omitted.

It was noted in the survey that benches are least successful in the sedimentary rock slopes since these are often prone to erosion. Fig. 5 shows gullying developing along the back of benches and in such materials benches are better omitted unless they can be fully turfed.

Benching is most successful in the stiff granitic soils where steeply sloping faces are possible, but even in these there appeared to be no disadvantage in omitting them in cuts up to 45 ft high.

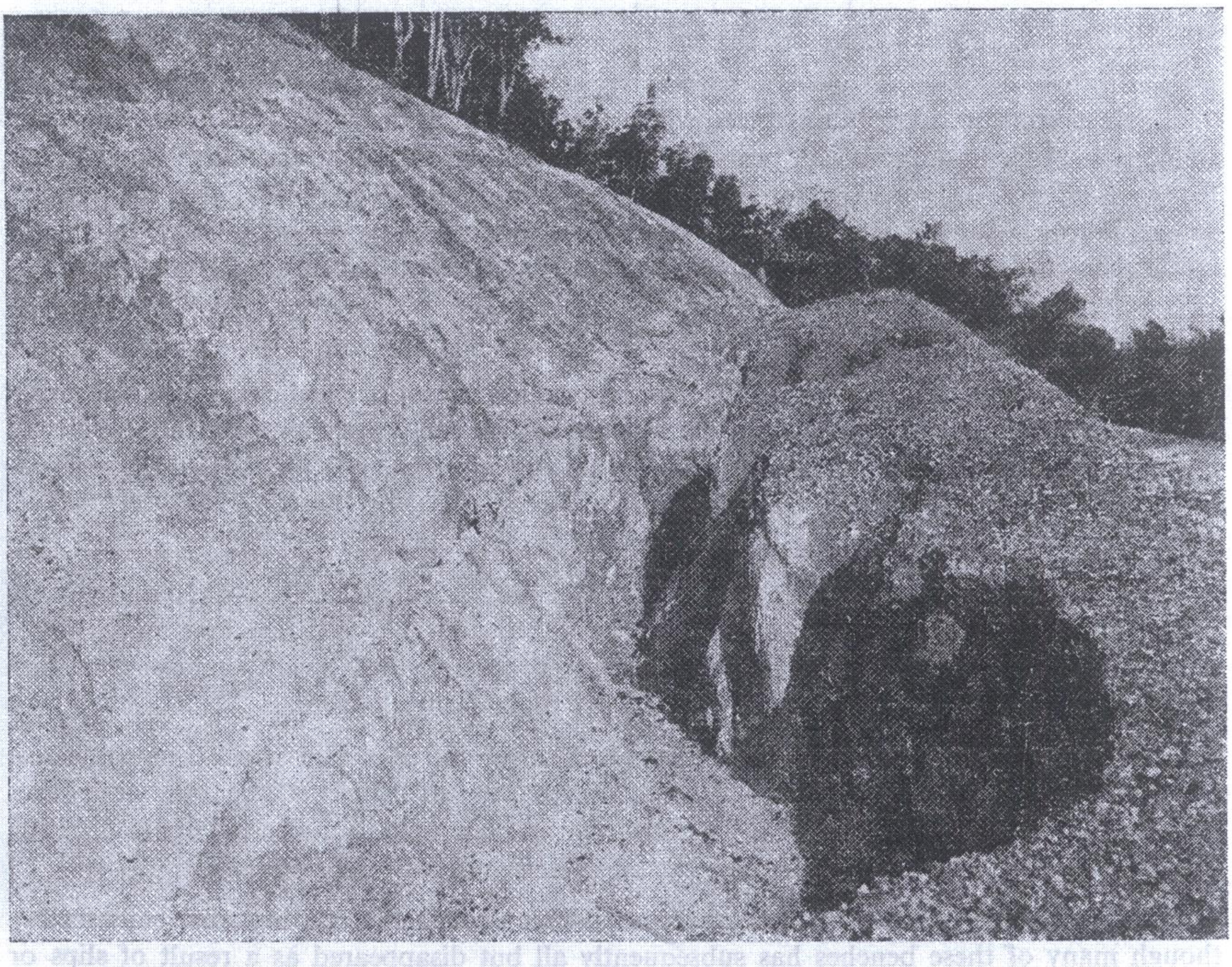

Fig. 5—Bench Erosion Developing in A New Shale Cut.

DESIGN RECOMMENDATIONS

In Table 2 a range of angles is recommended for each category of slope. Local conditions will determine the angle within the range appropriate to use for a particular slope. For instance, evidence of the presence of moving ground water would lead to the choice of a shallow angle in the range, whilst a decision to turf the face would permit a steep angle in the range.

The different categories of rock are identified by visual inspection when the ground is broken or from samples obtained from preliminary trial pits or boreholes. Particle size determinations may also be required. Reference to the local geological maps is always useful, particularly for recognising the sedimentary areas adjacent to igneous masses since these are likely to contain the troublesome 'soft' shales and phyllites.

On opening up a major cut it is helpful to first cut a narrow 'trench' 2 or 3 scrapers in width and about 20 ft deep so that the nature of the ground can be inspected first hand and final decisions made on the slope design before the future faces themselves have been reached. For instance, the position of faults or the orientation of joint planes revealed by such an inspection may make it desirable to construct the opposite faces of a double cut to different angles. The decision to bench or not can be left to this stage, and likewise the provision of a cut-off drain.

CONCLUSION

Preliminary analysis of data collected during an extensive survey of major road cuttings in western Malaysia has shown that the long-term slope stability characteristics of cuttings in residual soils and weathered rocks could be classified into seven basic categories. Recommendations are made for the slope angles in the various categories. Analysis of the data is continuing and should enable further recommendations on details of cut slope design to be formulated.

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