THE APPLICATION OF TERRAIN EVALUATION TO ROAD ENGINEERING

by

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SYNOPSIS

Terrain evaluation is the complete appraisal of the capabilities and limitations of an area of ground in relation to a particular kind of land use. The most widely used technique for engineering surveys is based on analysis of the ground, usually by means of air-photo interpretation, leading to the identification of mapping units. A map of this type has been prepared of about 18 000^2 km of West Malaysia, between Kuala Lumpur and Johor Bahru. This paper describes the relevance of terrain evaluation for feasibility studies and also in detailed materials investigations. The survey which can be extended into other areas could be used as the basis of a system of engineering data storage.

1. INTRODUCTION

The problems confronting the highway engineer may range from the planning of a road network for a new region of development to the location of a quarry, or the construction of a few kilometres of earth feeder road. Although the planning of a network will eventually lead to the preparation of actual projects, a different level of information is needed at each stage. The planning stage is concerned with the general costs and conditions, but must take note of differences in detail which could cause important variation in cost or design. In addition the information gathered in preliminary work should be relevant to the subsequent surveys for design and thus there is a need for a survey technique which can be used to relate information from one type of survey to another. Experience in many different situations has shown that terrain evaluation as described below, can be used in this way, and provides a suitable basis for all types of highway engineering surveys. The technique has been used most extensively in dry areas where vegetation is sparse, but recent experience in Malaysia has shown that it may also be used effectively where the ground is covered by trees.

2. TERRAIN EVALUATION

Terrain evaluation is the complete appraisal of the capabilities and limitations of an area of ground in relation to a particular kind of land use. The most widely used technique for engineering surveys is based on an analysis of the ground, usually by means of air-photo interpretation, leading to the identification of mapping units. The units recognised in this way are areas of ground whose recognisable form and observable characteristics result from the interaction of climate, geology and landforming processes. This means that where a terrain type can be identified in a new area the soil conditions will be identical with those of the type area. Thus by defining the soil conditions of interest to the engineer for a representative range of terrain units it is possible to appraise the engineering conditions of a large area.

The concept of survey by land classification was first described by Christian 1958 after it had been developed and used in Australia to express the agricultural potential of ground. Subsequently these concepts were expanded and modified in the United Kingdom by the Department of Agriculture at Oxford University, working under contract to the Ministry of Defence. The development of this work has been summarised in a paper by Webster and Beckett 1970. Similar studies had been made in South Africa and Australia, and in 1964 a joint meeting was held to define a common system of nomenclature (Brink et al 1966). This system recognizes seven categories of terrain, each defined by a combination of climate, geology and landform. The units are, in decreasing order of size:

- Land Zone
- Land Division
- Land Province
- Land Region
- Land System
- Land Facet
- Land Element

For completeness the whole classification is outlined here, although for most purposes users are only concerned with the lowest three units in the hierarchy. It is convenient to describe these three units first, as they constitute the basis of the classification from which the higher units are derived.

3. LAND SYSTEM, LAND FACET AND LAND ELEMENT

The processes of weathering and erosion interact upon the rocks at the earth's surface. The resulting topography reflects both the type of climate and the nature of the geology. The rocks weather and break down to form a mantle of soil that also reflects the geology and the process of weathering. Thus topography and soils both develop in response to the same environmental factors, and a given set of environmental controls will tend to give rise to specific land and soil types.

An area of ground weathering under fairly uniform geological and climatic conditions evolves into a small number of slope types or topographic units. The units are grouped into small associations, recurring over a wide area in a distinctive arrangement or pattern (Fig.1). This pattern of land forms is called a 'land system'. It is defined by the geology and climate and by its complement of small topographic units, called 'land facets'. The pattern persists to the limits of the geological formation upon which it is developed, or until the prevailing land forming process gives way to another. At this point a new land system is developed. Land systems can often be recognised on print laydowns at scales of about 1:100 000 by the distinctive appearance of their dissection, vegetation and land use patterns. By this means they may be tentatively outlined but they can only be properly mapped by delineating the limits of their complement of land facets. The recurrent association of groups of facets defines the extent of the land system: at the land system boundary all (or most) of the facets give way to a new association, in a different land system. A land system is named after a town or other geographical location, partly to aid its recall but more importantly to stress its restriction to a particular locality. Two landscapes that are apparently identical but distantly separated are initially given separate names, until it can be shown by more detailed soil mapping and test results that the landscapes may be considered identical. They will then both receive the name of the type locality. This avoids the possibility of grouping together two landscapes of different properties with insufficient evidence for their similarity.

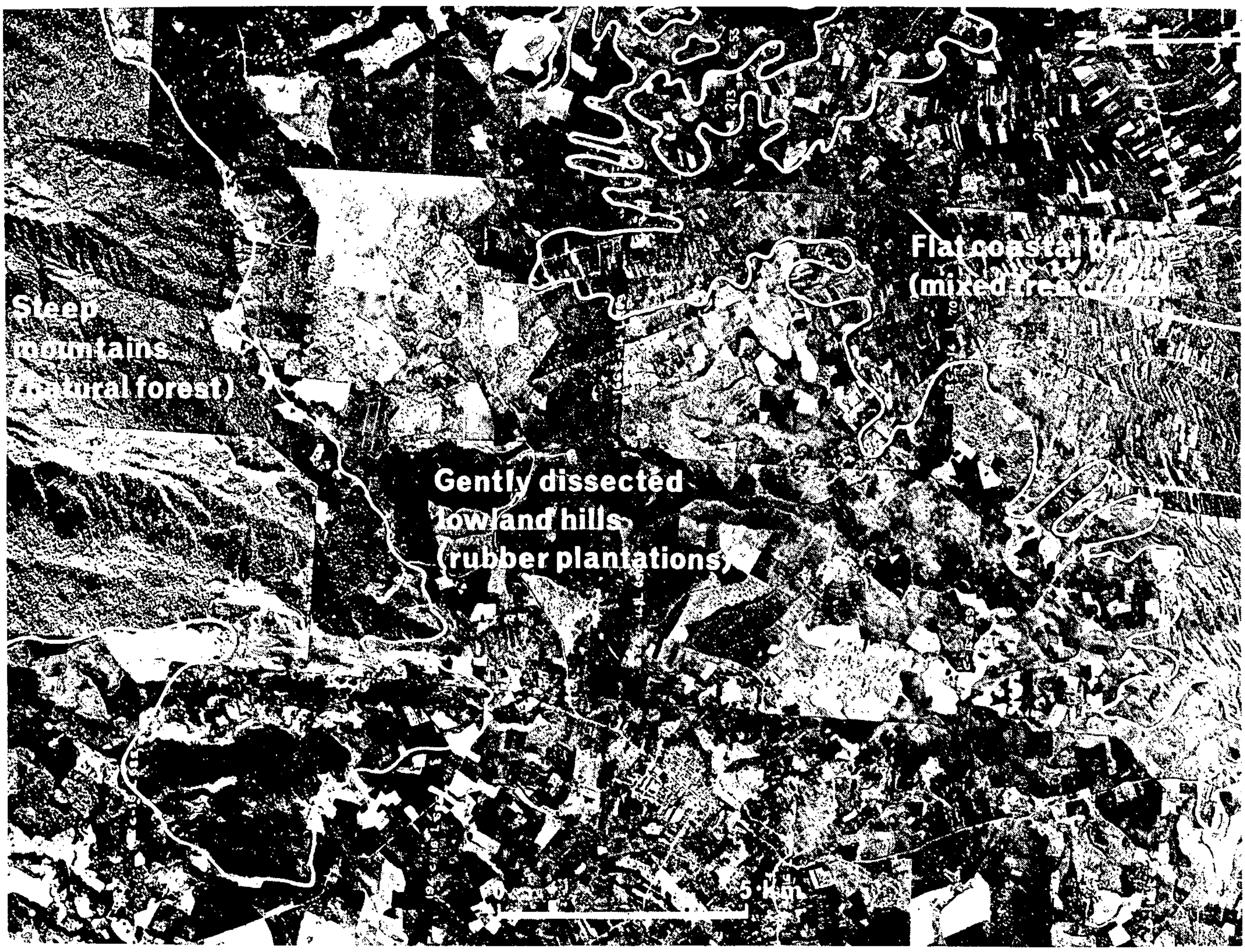

Fig. 1 Print laydown of aerial photographs showing the changes in air photo pattern between the coastal plain, the lowland hills and the mountains.

Land systems have been mapped elsewhere at scales of 1:500 000 to 1:1 million but in West Malaysia a scale of 1:250 000 is more appropriate for the complex terrain.

The land facet is the basic unit of mapping. It too is defined on its geology, water regime and topography, but in a much more restricted way than the parent land system. A land facet has a simple form (it would fit into one slope class in a slope map), a fairly homogeneous parent material and a single water regime (both surface water and ground water). The materials developed on it are naturally fairly uniform, such that a pedologist would map its soils at approximately association level, and an engineer would accept a single design specification for a section of road built on it. Land facets are normally mappable at scales up to about 1:50 000, but in West Malaysia a larger scale (1:20 000–1:30 000) is necessary as the facets tend to be rather small.

It frequently happens that a very small feature of the landscape is of particular significance to a proposed scheme. The feature is too small to be mapped, but is nonetheless important enough to warrant a special category. In this case a 'land element' is recognised, the smallest unit of landscape that is normally significant in preliminary and perhaps detailed surveys. For example, a hill slope may consist of two land elements, a steep upper slope and a gentle lower slope. To an engineer each slope element is important when considering slope stability and amounts of cut and fill. Other examples of land elements are very small river terraces, gully slopes and small rock outcrops.

The occurrence of one or more land elements in a particular facet is predictable, although they are not necessarily always present. The relationship between the land system, land facet and land element is illustrated in Fig.2.

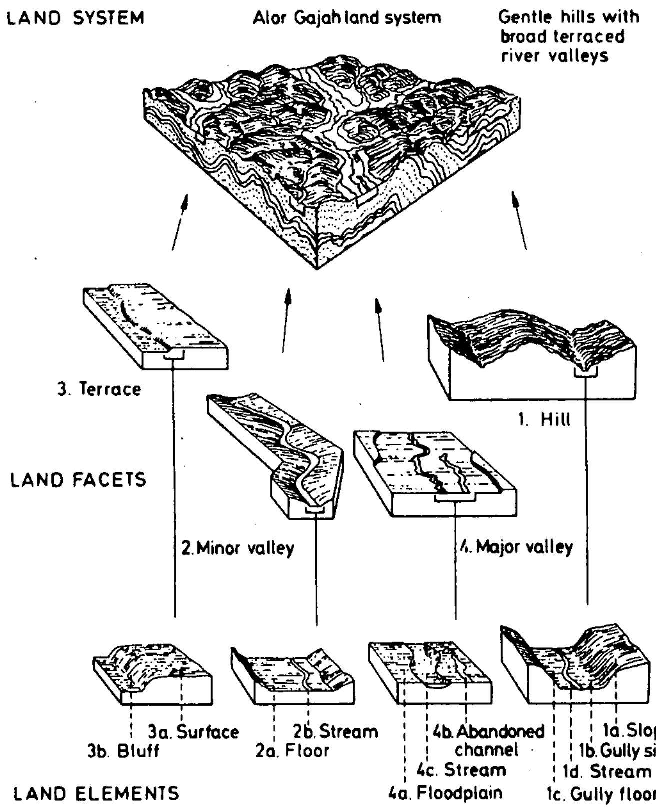

Fig. 2 Diagram to show the relationship between land system, land facet and land element.

4. OTHER LAND UNITS

The land system, land facet and land element are the main units of the terrain classification. The land region is made up of a group of land systems having the same basic geological composition and an overall similarity of landforms. The lowland granite land region and the lowland sediments land region of West Malaysia are examples. It has been found convenient to group the land systems of south West Malaysia into land regions, on the basis of soil test results. Other categories of terrain unit, designed to accommodate the minor variations in landscape and materials that inevitably occur in Malaysia, are described by Lawrance 1972, who also discusses the technique and problems of terrain classification in West Malaysia.

LAND SYSTEM MAPPING

Land system maps have been prepared for large parts of Africa and Australia and have been used by engineers to prepare highway engineering surveys, (Australian Road Research Board 1968). Apart from work in India, most of which is restricted, (Kayerker 1969) little use has been made of land systems mapping for engineering use in Asia to date.

The TRRL has now prepared a land systems map of the area between Kuala Lumpur and Johor Bahru, which has been printed by the Directorate of National Mapping in two sheets. The maps which cover some 18 000 km^2, are at a scale of 1:250 000 and comprise 42 land systems which have been grouped into 16 land regions. The colours on the maps have been used to emphasise the distribution of land regions, since soil test results show a greater difference between the land regions than the land systems, (Beaven, Lawrance and Newill 1971). All land system boundaries are also marked since they do show differences in soil type in some cases, and they also represent different types of topography. The map will be issued with a report describing the form and properties of each land system. A typical description of one of the land systems is shown in Fig.3 and Table 1.

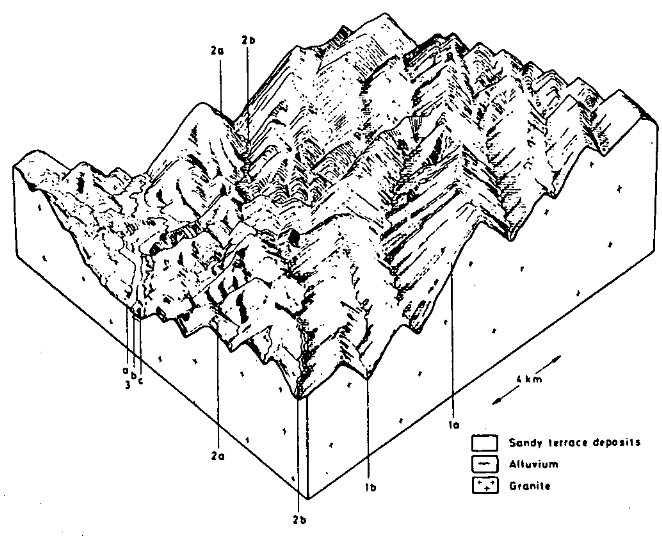

Fig. 3 The Beremban land system. See Table 1 for description

TABLE 1

ENGINEERING CHARACTERISTICS OF THE BEREMBAN LAND SYSTEM

Land Facet	Form	Soils, Materials and Hydrology	Engineering Properties and Comments
1	Ridges and valleys Steep V-shaped valleys arranged roughly parallel or radially with long narrow ridge crests. Major ridges dissected by successively smaller straight V-shaped valleys. Local relief 100-375 m. in main valleys. (a) Valley sides: slopes long, straight, 20–30° (locally steeper). May be studded with core boulders up to 3 m across.	Weathered granite from 0-20 m. Lateral variation of depth occurs rapidly, tending to be greatest on ridge crests and least at sites of stream sapping. Usually contains coarse angular quartz grains in a matrix of completely weathered felspar and mica. Junction with hard unweathered rock usually very abrupt, but there may be an intermediate zone of soft, partially weathered granite. Core boulders of hard granite.	Two types of engineering soils: (i) comprising coarse angular quartz grains in plastic silty clay matrix, (ii) rock in different stages of weathering. Both soil types are freely draining – good subgrade and fill material. Extensive earth-works required, usually in side-long ground. In cuttings recommended angles for slopes are for soil type (i) 50–60°, for soil type (ii) 50–70°. In deep cuttings rock blasting may be necessary. Steeper slopes may need retaining walls to hold fill. Fill slopes may need protection from erosion. Quarry sites best located in steeper ground. Stone suitable for crushed stone bases, road surfacing and concrete aggregate.
	(b) Stream 1–few m across, flowing in narrow channel but usually not incised.	Usually permanent streams.	Liable to swell rapidly after rain. Danger of damage to drainage structure from floating debris.
2	Foothills (a) Ridge crest strongly convex, about 40–60 m across. Slopes are straight, 15–20°, and occasionally 35°, may be smooth or uneven in detail, according to presence or absence of core boulders near surface.	(a) As facet 1	As facet 1
	(b) Small valley bottom. Gently concave and 10–20 m across.	(b) Granite wash. Orange or yellow-brown sandy clay becoming red at 1–2 m and coarser and more silty with depth. Profile to weathered granite may be 2 m or more deep. Impeded drainage.	Alluvial materials; stable subgrade provided road is kept above water table level.
	(c) Small stream. Few m wide, indenting hill sopes, or sometimes strongly dissecting them into short irregular ridges.	(c) Temporary, flowing after rain.	Small culvert needed; some danger of blockage by vegetation after storms.
3	Major valley (a) Footslope and terrace. Level to very gently sloping; may be discontinuous in a valley 100–200 m and occasionally 300 m long; 50 m and occasionally up to 200 m wide or continuous when associated with a flood plain. Here it is 50–150 m wide, with a small bluff (1–2 m high) to the floodplain. May possess a few small gullies.	Granite wash, as 2(b) in the higher valleys. Terrace deposits variable but mostly pale-coloured clayey sands, freely draining.	Terrace materials good subgrade and suitable for fill.
	(b) Floodplain. Level,50–300 m wide, extending up to 5 km into land system. Not a common element.	Very variable, texture ranging from sand to clay depending on distance from source. Very weak profile development. High water table.	Wet plastic soils requiring an embankment. Liable to flood.
	(c) River channels. Few m to 20 m wide, sinuous, may be incised 1–2 m into floodplain.	Permanent flow, but liable to swell rapidly after long periods of rain.	Bridge crossings required. Danger of damage to structures from floating debris.

6. THE APPLICATION OF TERRAIN EVALUATION IN HIGHWAY ENGINEERING

The second part of this paper is concerned with the use of land system mapping to assist the highway engineer in different types of survey. It is not necessary to have a complete land system map prepared for the whole country before starting to use terrain evaluation. In many cases it is sufficient to study the relevant parts of the survey area. However, it is obviously easier for an engineer to use an existing map then to prepare his own terrain classification, and when extending the possibilities of the system to provide a national data bank, it would be necessary to prepare a national map.

7. ROAD NETWORK PLANNING

At the early stages of planning, generalised information is needed on soils, materials, and engineering problems. The technique of terrain evaluation can provide a rapid and effective method to summarize the relevant data and this was demonstrated in the preparation, by consultants, of two development plans in Johore. The two areas concerned included part of the area covered by the Land System map, but the greater part was unmapped. Using experience of the adjacent areas, two members of the TRRL mapped provisional land system boundaries for more than 2000 square kilometres in one day, using 1:63 360 scale topographical maps, together with geological and soils reconnaissance maps. From a knowledge of the properties of the land systems, it was possible to prepare a brief report summarising the behaviour of the main soil types, with estimate of pavement thickness for lightly trafficked roads; this would be accurate enough to calculate quantities of base material for this level of survey. It was also possible to state that stone was available in the area, and to indicate the general location of quarry sites and to comment on the approaches to the one major river crossing in one of the areas. These two days work in Johore, which could have been spent before the project started, provided the highway engineer with the background information needed to plan his road network.

8. ROAD LOCATION

The section of the East-West Highway in Nepal which is being constructed by the British government provides an example of the use of terrain evaluation at an early stage of a project. As a result of these studies certain sections of the route were realigned, and the search for road base materials was organised on a rational basis.

The eastern section of the road, Fig.4 runs roughly east-west for 56 km, constrained on the north by an east-west range of mountains, and on the south by the Narayani River which also flows in a westerly direction over this length. In between the lower slopes of the mountains and the flood-plain of the river lies a complex arrangement of terraces with a well-defined piedmont fan system extending southwards from the foot of the mountains.

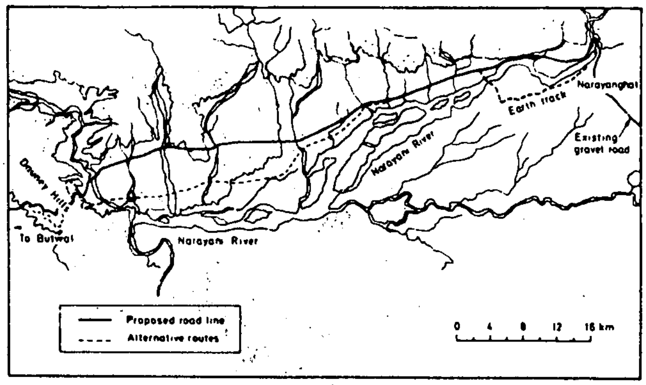

Fig. 4 Butwal to Narayanghat Road Nepal

The air photographs of the area, which are at a scale of 1:12 000, were examined first as a photo mosaic, and then stereoscopically. The main terrain types were delineated and potential sources of gravel, old stream channels, terraces and areas liable to inundation were marked on the photographs. Particular attention was paid to identifying the best crossing points for the three large rivers and several smaller rivers in this section of the route. The original line traversed low-lying terraces and flood-plains of fine-grained plastic soils used for wet-padi cultivation and it involved the crossing of wide ill-defined water-courses.

It became clear that a relocation of the road some one to three kilometres north of the original route would bring a substantial reduction in cost and a greater immunity against flooding. An alternative, more northerly, route was traced out traversing elevated well drained gravel-bearing fans and crossing the principal water courses at points where they are narrowest and most stable, thus permitting bridges above flood level at a reasonable cost.

In order to compare the relative merits of the two routes in this section, rough quantities were taken off by scaling from the air photographs. The quantities were based on the following assumptions:-

(i) that a 3.7 metre wide base and 9.1 metre wide formation would be provided on both routes;

(ii) that subgrade level would be a minimum of 1.2 metres above the normal standing water level in flooded padi fields; and

(iii) that bridges of similar standard would be provided on both routes.

Arbitrary unit rates were applied to these quantities which, when grossed up, showed a cost difference of the order of £750 000 between the two routes, the alternative northerly route being the cheaper. Whilst it was appreciated that this figure was only a crude estimate of the potential cost difference between the two routes it was felt that there was ample justification from the purely engineering point of view to direct subsequent survey and design effort on the northerly alignment.

9. MATERIALS INVESTIGATIONS

Materials for highway construction include fill, sub-base and base materials, together with sources of aggregate and sand for concrete. The use of terrain evaluation in materials survey can be illustrated by a recent investigation for quarry sites around Kuala Lumpur. There are two main aggregates in the area, granite and limestone. As the limestone, which polishes rapidly and is unsuitable for a road surfacing, is already quarried extensively, it was required to identify potential quarry sites on the granite. From previous knowledge of the area, it was known that suitable sites could be found in the area of granite mapped as the Beremban land system (Fig. 3), and that in other areas of granite the overburden would be too deep.

With this information, the air photographs of the area were examined stereoscopically to identify possible sites. The main feature sought for was steep ground where erosion of the soil would lead to minimum overburden. Access to the site was also considered an important feature, and from several potential sites, one was selected for further investigation. A preliminary evaluation of this site was made by a seismic refraction survey, which showed that the overburden increased from 2 metres thickness at road level to between 3 and 8 metres thickness at 30 metres above the road (Fig.5). Thus in a short time the site was identified and enough information gathered to justify a drilling programme to prove the extent and quality of the rock.

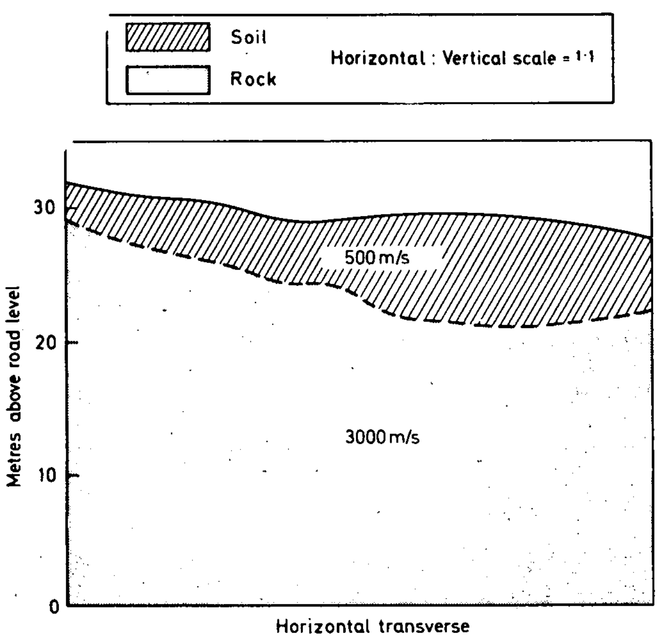

Fig. 5 Results of seismic refraction survey over granite quarry site, Kuala Lumpur

10. DATA STORAGE

All engineering work, whether it be a soil survey or the construction and performance of a road, leads to the acquisition of information. The factual information is usually stored in files, some of which may be processed for publication. Experience tends to be remembered rather than recorded, and thus can only be reapplied where a person with the appropriate background is presented with a new problem. General information of this type can also be recorded and filed, but this increases the data store, and magnifies the task of selecting the relevant information. Thus a major problem in setting up a usable data store is to design a classification system that will allow access to information of varying quality and type, but present all known relevant data concerning a particular problem.

The flexibility of the system of terrain classification used in engineering surveys suggests that it can be used as the basis for such a data store. The information given in Table 1, in conjunction with Fig.3, is a simple presentation of a range of information including land form, soil profiles, and recommendations for engineering practice. In this type of record, which could be extended to other areas to form the basis of a national data store, some reduction of data is necessary to simplify the wealth of detail available. With more elaborate methods of data storage, the same classification system could still be used to record the data in total.

11. CONCLUSIONS

Work in Africa, Asia and Australia has shown that terrain evaluation can be used for mapping and classifying the engineering features of the ground. The particular advantages of the sytem are:

1. The classification consists of units which are easily recognisable both on the ground and from aerial photographs. Although it is usual for a specialist to prepare the classification, the units can then be identified and mapped by engineers.

2. At the level of the land system, broad but useful generalisations can be made about the properties of soils, availability of road-making materials,suitable methods of construction and particular problems likely to be encountered.

3. Land facets and land elements classify terrain at the level required for road projects and provide a means to record information about the materials at a site. In this way it is possible to predict the properties of terrain in different areas, e.g. the location of a quarry site, or a recommendation of pavement design.

4. The recognition of the limited number of landscape units in an area gives a preliminary assessment of the variation of materials to be expected. This can then be used to decide the appropriate places and frequency of sampling to provide adequate information for design purposes. In this way excessive sampling can be avoided, but the risk of overlooking a small but important variation is minimised.

5. The terrain evaluation classification for engineering purposes is similar to that widely used for agricultural and other land use surveys. This will assist in the integration of engineering surveys with surveys for land development.

6. The terrain units provide a suitable classification for the recording of all types of information relevant to highway engineering. The advantage of recording the information against a terrain classification is that it simplifies the task of extracting the relevant information from the store and translating it to a location on the ground.

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