GEOSEA V Proceedings Vol. II, Geol. Soc. Malaysia, Bulletin 20, August 1986; pp. 857–869

The integration of remote sensing, terrain evaluation and engineering geology in Southeast Asia

T.E. BEAUMONT AND T. HUNT
Scott Wilson Kirkpatrick and Partners
Scott House, Basingstoke, Hampshire, RG21 2JG, England

Abstract: The efficiency of geotechnical and engineering geology surveys in undeveloped regions can now be significantly improved by integrating data made available from the latest remote sensing surveillance technology with the well established methods of terrain evaluation and ground sampling procedures. A strategy is outlined and illustrated by recent case studies in Southeast Asia, how information acquired from the interpretation of remote sensing data can be utilised in geotechnical appraisals of terrain for engineering purposes and integrated with terrain evaluation for establishing database and management systems.

INTRODUCTION

The improvement of rapid methods to appraise the physical properties of terrain for planning, site investigation and engineering geological studies is becoming increasingly important in remote and inaccessible regions where effective decisions about the location and design of new infrastructure are quickly required within both national and local development programmes. Efficiency and accuracy of engineering geological surveys in these areas can now be significantly increased by integrating data made available from the latest remote sensing surveillance technology and the well established methods of terrain evaluation deploying aerial photography, and ground sampling procedures. In utilising this useful and cost effective source of information, maximum returns may be achieved on survey effort and the expenditure of usually scarce financial and skilled human resources.

Economic necessity and diversity of physical environments requires geologists and engineers to make best use of available natural resources in Southeast Asia. This is frequently emphasised where planning decisions are influenced by consideration of adapting complementary economic and technical factors to meet special needs and local conditions. For example, utilising to full advantage available natural road building materials is often significant with respect to route location and related aspects of minimising construction, maintenance and vehicle operating costs. The Engineering Geologist however, in assessing materials and other geotechnical factors has to acquire a considerable amount of information on the nature of the terrain through which the road will be built. Acquisition of basic survey data is similarly fundamental to studies of geology and related planning, exploitation and management of mineral and energy resources in Southeast Asia.

The interpretation of existing black-and-white and more recently colour aerial mapping photography has traditionally proved invaluable to the Engineering Geologist in the preliminary collection of data relevant to the selection of the alignment, design and method of construction of roads in tropical environments. Improvements in the collection and analysis of data through the advent of remote sensing surveillance programmes have further emphasised the value of such indirect reconnaissance survey methods to overcome the limitations imposed in remote areas by the lack of relevant information on the local geology, occurrence of construction materials and engineering properties of the terrain. Optimum results may now therefore be attained in overcoming many of the problems associated with very large and often inaccessible areas by integrating information derived from interpreting satellite and radar imagery with established terrain evaluation procedures. The improved opportunities to recognise available ground options at an early stage in the planning process are also significant and of value with respect to ensuring costly effort put into site investigation and detailed ground survey is not misplaced.

THE ROLE OF TERRAIN EVALUATION IN GEOTECHNICAL STUDIES

Airphoto interpretation has, for many years, proved to be invaluable for geotechnical studies of terrain and especially engineering materials surveys. In addition to identifying potential sites from the characteristic tones, textures, and other elements of the airphoto pattern, the three dimensional view of the landscape obtained by stereoscopic viewing of aerial photographs often provides evidence of past and present geomorphological processes and allows specific landforms to be delineated which, because of the nature of their origin, are likely to contain the particular materials sought. This physiographic approach to locating construction materials forms an integral part of the terrain evaluation method of appraising ground for engineering purposes, whereby the ground conditions and associated geotechnical considerations are related to a land classification scheme where homogeneous units of land are initially identified by their distinctive airphoto patterns (Dowling and Beaven, 1969; Mitchell, 1973; Aitchison and Grant, 1968).

The principles of land classification involve the recognition of distinctive patterns of landscape, brought about by the interaction of the many different components that make up the natural environment, such as rocks, soil, topography, vegetation and climate. One of the most important concepts of the land classification approach to studying terrain is that, in any number of different situations where these components have the same character and operate together in a similar manner, the physical form of the landscape will be essentially of an identical nature.

Most engineers and geologists are aware of the repetitive nature of ground and, in regions that they know well, would easily recognise associations between certain rock types, hill shapes, soils and vegetation. Land classification simply sets out to define and record these relationships more accurately. When the various features of landscape have been described the next step is to obtain values for the physical attributes of different portions of the landscape. In this way, a land classification becomes a terrain evaluation and when the values obtained are concerned with soil strength, rock stability, plasticity or any of the other properties on which the design of engineering works is based, the ground can be said to have been evaluated for engineering purposes. To the Engineering Geologist, the importance of terrain evaluation lies in its ability to deal with a wide variety of engineering considerations which are not restricted to soils, but, in addition, include information about properties of rocks, relief, geological structure, hazards and hydrology. Moreover, because patterns of landscape can easily be identified using aerial photography, and now remote sensing data, large areas of ground can be examined quickly.

Terrain evaluation methods have now been used in most countries throughout Southeast Asia. In West Malaysia, for example, the technique was successfully used for highway planning and feasibility studies (Beaven and Lawrance, 1973) where besides the rapid production of a reconnaissance engineering soil map, the measurement of terrain factors used to link other criteria affecting road design to the land classification included geotechnical design of cuttings, quantities of earthworks, foundation conditions, and frequency and size of culverts. Significantly, in countries such as Malaysia, the land classification into which the information is placed facilitates its easy withdrawal and allows extrapolation to be made into areas which are often inaccessible and unlikely to be subject to detailed ground inspecticn (Lawrance 1972, 1978).

The system of land classification resulting from the terrain evaluation study can also provide the working basis for a method of data storage in which information collected, and experience gained, on engineering projects is able to be kept for planning purposes and future use. As the terrain evaluation classification for engineering purposes is similar to that widely used for agricultural and other land use investigations it can also assist in the integration of engineering and geotechnical surveys with those required for land development. Additionally, the use of an established data storage system will prevent wasteful repetition of survey effort and facilitate the transfer of engineering data and experience in construction and resource utilisation to similar areas throughout Southeast Asia.

DEVELOPMENTS IN REMOTE SENSING SURVEY TECHNIQUES

Over the last ten years, engineering geology and geotechnical information derived by air survey methods has been expanded and refined by making use of the different forms of remotely sensed data and related developments in interpretation techniques that have recently become available (Beaumont 1979a, 1984). True and false colour film emulsions with their greater range of tonal information have been particularly successful in materials surveys (Mintzer *et al.*, 1983), while further potential appears to lie in the deployment of multispectral techniques using various film-filter reflectance differences, and hence best tonal contrasts, exist between features of interest.

Recent attention has similarly been focussed on the value of 1:50,000 or smaller scale, high altitude infra-red photography for terrain evaluation studies, as the large regional coverage per photograph and excellent resolution characteristics of the film make it possible to evaluate both regional factors and local detailed features. Interpretation of specific details is usually facilitated by making use of a stereoscope or viewer with high magnification capabilities, or by producing photographic enlargements. The economics of using such data are explained by the fact that to perform a stereoscopic evaluation of 256 sq Km of ground requires approximately 7 photographs at a scale of 1:80,000 versus approximately 70 photographs at a scale of 1:20,000. It is for these reasons that much interest is currently being expressed in the development of space photography with the European Spacelab Metric Camera and the NASA Large Format Camera programmes operated from the Space Shuttle or possible future space station platforms. Significant data, including height information, has already been able to be acquired on the terrain of Southeast Asia by means of this type of small scale space photography (DFVLR, 1984).

The deployment of different sensors from aircraft and space platforms has emphasised the importance of the overall fundamental principle of multi- spectral sensing for discrimination of different types of material which is illustrated in Figure 1. The reflectance curves for the four different rock types show the distinct higher reflectance of the brown sandstone at the

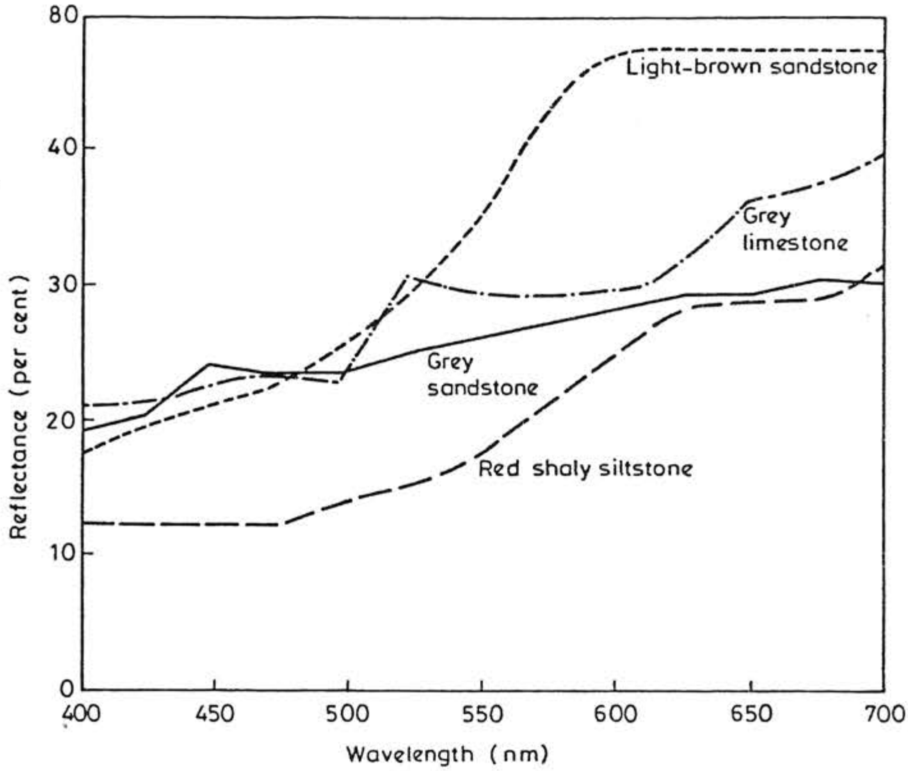

Fig. 1. Spectral reflectance curves for fresh samples of four different rock types (After Ray and Fischer, 1960).

longer (orange-red) wavelengths and the relatively lower reflectance of the siltstone in the shorter (blue) wavelengths of the visible spectrum. On a black-and-white aerial photograph it would be relatively difficult to distinguish between these rock types, but if reflected energy from the short and longer ends of the visible spectrum were recorded separately, differentiation would be straightforward (Ray & Fischer, 1960). When imagery is also recorded by different sensors within wavelengths outside the visible spectrum, the capability to distinguish between different materials increases, as their spectral characteristics, being dependent on atomic and molecular structure, are also selective with regard to wavelength. In short, recent developments in remote sensing devices, such as the multispectral scanner, and related interpretation techniques are able to discriminate more accurately between different surface materials and related features, as they have distinctive 'signatures' in terms of their reaction to energy throughout the electromagnetic spectrum.

One of the main questions facing the highway engineer about to undertake a materials survey in a developing country is what alternative sources of survey information are available in the frequent situation where an adequate coverage of aerial photographs or topographic maps does not exist or cannot be obtained over the area of interest. In many equatorial areas which are rarely cloud free, great use has recently been made of the all-weather, day and night capability of radar to provide small-scale imagery over large regions. Radar coverage now exists for the whole of Papua New Guinea, much of Indonesia and large regions of other countries throughout Southeast Asia.

Imagery recorded by radar systems has many characteristic attributes; for example, the great detail of landforms revealed due to the low angle of incident illumination, which can be extremely useful in providing information for materials location, geotechnical surveys and engineering planning (Simonett and Davis, 1983; Williams *et al.*, 1983; Orr and Quick, 1971).

The most significant recent technological development to overcome the lack of survey information in countries of the developing world has been the combination of new types of sensors with a space platform. Observation of the earth's surface from space overcomes some of the limitations of aerial photography which arise from restrictions on (a) the area that can be covered in any one photographic scene, (b) the cost incurred in covering very large areas, and (c) the degree of uniformity that can be achieved in repetitive coverage of the same area or different areas with the same lighting conditions. The large regional views provided on imagery repetitively recorded in different wavelength bands by the multispectral scanner on board the Landsat satellites may now be interpreted for the rapid location and mapping of engineering construction materials over very large areas, and for other data relevant to engineering geology and geotechnical planning. This low-cost information, which is easily obtained and available for most of the land areas of the world, is of special value for those projects undertaken in areas where land resource information, suitable maps, and airphoto coverage are frequently not available (Beaumont, 1980).

In emphasising the value of satellite imagery in regions of poor map coverage and where sources of relevant information are limited, attention must also be drawn to the main limitation of cloud cover which can adversely affect the deployment of Landsat data in equatorial climates. This problem is likely to be overcome in the future however, if the low altitude equatorial orbiting satellite, TERS, designed to detect and acquire imagery through gaps in the cloud cover, and currently under joint development by the Dutch and Indonesian Space Agencies, is funded for operational use. In the meantime however, Landsat imagery should still prove to be useful when recorded in these climatic zones, especially if deployed in tandem with orbiting radar systems, such as the SIR-A recently in operation on the Space Shuttle flights, which have a greater ground resolution and all- weather, day and night capability.

Continuing improvements in the spectral sensitivy and spatial resolution of satellite data, as evident in the current Thematic Mapper imagery of Landsat 5 and future satellite systems such as SPOT, coupled with increased sophistication in image processing and interpretation techniques to extract relevant information, will result in even greater reliance on the use of remote sensing survey methods. The significant capability of this new technology to acquire information for engineering geology and geotechnical studies is already acting as a catalyst to induce necessary change in planning practices which have become evident in the recent developments to use remote sensing and terrain evaluation methods to establish regional engineering and geographic information database systems for management purposes. This development is likely to become more widespread throughout Southeast Asia as pressure increases to conserve or make better use of finite natural resources.

REMOTE SENSING IN TERRAIN EVALUATION AND MATERIALS INVENTORY

Recent emphasis on the construction of low-cost, rural feeder roads and other infrastructure in developing countries has also drawn attention to the value of regional or national inventories of road-building materials. Until recently, few attempts have been made to compile data on nationwide resources of engineering materials, even though their location and proving accounts for a substantial proportion of total costs and time spent on most engineering projects. However, recent studies have proved that a national data store of engineering materials information can prevent wasteful repetition of survey effort in developing countries and, moreover, by the application of the terrain classification concept, facilitate the transfer of information from one area to another (Lawrance, 1977). Remote sensing studies have also proved very effective for locating and mapping engineering construction materials (Beaumont, 1979b). The strategy employed to inventory material resources over such large areas relies on the use of land classification based on the interpretation of remote sensing data, to form a rational sampling programme and framework, whereby field and associated test data can be placed in a properly ordered setting in relation to the terrain.

In those areas of Southeast Asia where adequate aerial photographic and topographic map coverage is limited and insufficient data on geology and soils provides an additional handicap to geotechnical investigations, it is envisaged that preliminary information for planning purposes may now be acquired from available radar and Landsat satellite imagery. Lack of information on the occurrence of construction materials, and engineering ground conditions especially, may now be largely overcome by using established terrain evaluation procedures in conjunction with the global coverage of large regional views provided by satellite data and other recent technological developments in remote sensing survey techniques. In making the best use of available natural resources it is advocated that those involved with planning in the highways and public works sector should deploy cost-effective, rapid remote sensing survey methods to locate, map and inventory indigeneous road construction materials so that their use can be appropriately matched in the most suitable way to the road transport needs and climate of the country concerned.

An outline flow diagram is shown in Figure 2 for integrating remote sensing image interpretation with conventional analysis of aerial photography in a typical terrain evaluation and mapping study undertaken for geotechnical or engineering purposes. It will be evident from this flow chart that the scale of the image products generated for interpretation are of crucial importance with respect to the land classification hierarchy and design which can be implemented for mapping requirements, and that the option to use digital computer processing techniques to enhance and interpret the remote sensing imagery is directly related. Where problems arise due to the resolution capability of the available imagery being inadequate for mapping specific detailed features of interest, previous experience has demonstrated the validity of employing a multi-level, double sampling regression technique for allowing the capabilities of Landsat and other small scale image data to be effectively combined with the more detailed information gathering procedures of airphoto and ground based surveys (Latham *et al.*, 1983). It is also envisaged that this double sampling regression technique would greatly assist in overcoming similar problems arising from dense vegetation cover obscuring ground conditions.

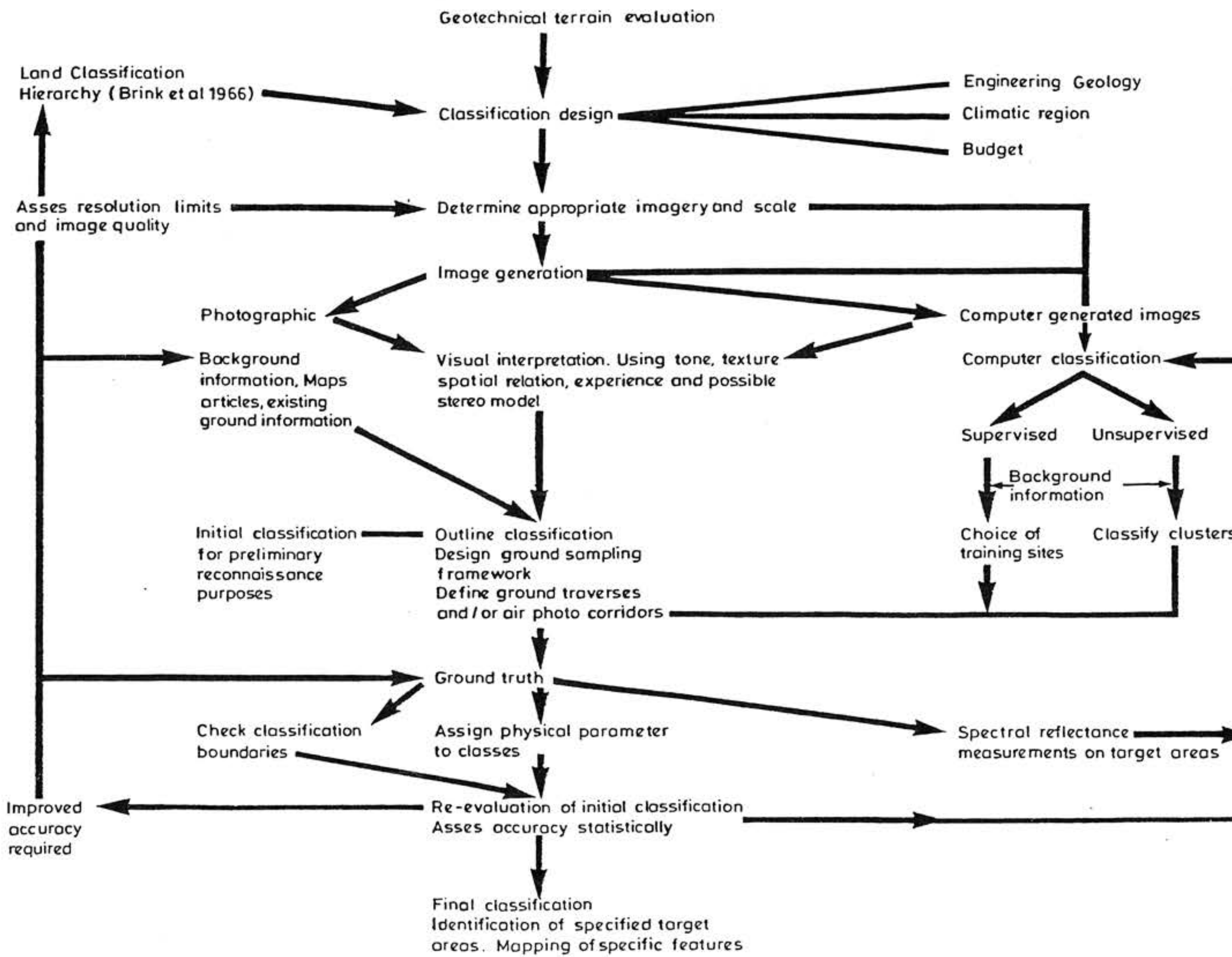

Fig. 2. A flow chart for the integration of remote sensing data in a geotechnical terrain evaluation study.

The formulation and execution of a discrete development project generally imposes the most stringent demands for natural resource and environmental information. In undeveloped regions the use of Landsat imagery for initially providing a baseline inventory of a physical resource over a large region, and subsequently monitoring its development, exploitation or conservation, is now becoming widely accepted (N.A.S., 1977). This awareness of the value of Landsat data is becoming increasingly important to those engineers and geologists working in teams where technical staff from different disciplines are required on a project to link one set of data with another. Integrated use of resource information is desirable and can be achieved in the design and execution of a development project. even in countries where such information remains fragmented at the national level.

In the rural sector the successful planning and implementation of regional development involves much more than improving the basic techniques in any sector in order to increase production based on natural resources. Experience has shown that virtually all sectors of activity are closely interrelated in mineral, energy, natural resource appraisal, and regional planning or rural development programmes. Economic, mineral, energy, agricultural, physical and social development must be planned so that they can be achieved together. Landsat satellite or radar imagery, and associated larger-scale remote sensing data, can provide a useful framework for attaining this objective, whereby on the basis of image interpretation, different specialists can be coordinated within a fully integrated programme. The ability of remote sensing data to provide a framework for integration will significantly increase in the future with the advent of geographic computer database and management systems.

REMOTE SENSING AND TERRAIN EVALUATION IN PRACTICE

The following studies have been selected with the intention of demonstrating the very wide scope and range of application for the use of remote sensing and terrain evaluation methods in current engineering geology, geotechnics and engineering planning practice in Southeast Asia. As space does not allow a full discussion of technical detail, a brief summary is given for each project outlining the contribution made by remote sensing and terrain evaluation in the overall programme. Wherever possible sources of reference are given for ascertaining full details of the relevant project.

Bangladesh transport study

In 1972 a study was initiated with the objective of determining the optimum transport investment policy for the whole country of Bangladesh and its population of over 80 million. The survey carried out covered the entire country and all modes of transport, and included the collection and analysis of large quantities of data on the existing transport system and its condition; on the cost of transport by different modes; on the current organisation and administration of the transport industry; and on the construction and maintenance techniques used. Within the overall study, major surveys had to be undertaken of the water, roads, rail and air transport systems which necessitated a review of design and construction standards and the drawing up of a master plan for future infrastructure investment.

A major requirement in evaluating design and construction specifications for future improvements to roads, canals, airports, ports and railways concerned the acquisition of viable geotechnical information on the physical properties of the terrain with respect to foundation conditions, hydrology, sources of construction materials etc. The need to collect these data was further emphasised by the poor status of existing records resulting from the conflict between East and West Pakistan and the recent emergence of Bangladesh as an independent nation. To acquire such information for the whole country within the relatively short study programme posed a major problem which was only able to be overcome by using terrain evaluation methods in conjunction with existing airphoto mosaics, aerial photography and newly available Landsat satellite imagery.

After evaluating existing agricultural soils maps prepared on the basis of airphoto interpretation, a terrain evaluation survey was undertaken for the whole country using satellite imagery to provide a synoptic overview in association with the analysis of airphoto mosaics and aerial photography for more specific detail. On this basis an engineering soils map was prepared which additionally illustrated the distribution of different land systems initially designated within the land classification scheme. Engineering attributes, soil types, foundation problems, and typical subgrade CBR values were also detailed for each land system and wherever possible individual land facets. The complete survey of over 60,000 sq Km was carried out in a total period of 5 months and provided a sound basis of information which substantially contributed to the final presentation and recommendations of the study (SWK, 1974). Additional information was also able to be included within the terrain evaluation on socio-economic parameters relevant to the transport sector review, and as such, the remote sensing/terrain evaluation data provided a useful framework to integrate different geographical aspects of the study programme.

Landsat satellite imagery was of immediate use at the commencement of the study in enabling an appreciation to be gained of the different physiographic regions of Bangladesh; in providing an up to date base map of the country, and in studying soil types and surface hydrology. Although it proved difficult to identify sources of construction material other than already known hilly site areas, major fault and fracture patterns could be determined through interpretation of lineaments which assisted in appraisals of structural geology with respect to likely depths of major potential sources of suitable rock located below overlying sedimentary deposits. The multispectral characteristics of Landsat data however also assisted airphoto interpretation studies to identify river boulders, sands and gravels which formed a major supply of construction materials in northern and to a lesser extent eastern Bangladesh. Other especially useful information interpreted from the imagery included assessing changes in river courses, mapping areas of deposition and accretion within the coastal zone, identifying areas of excess soil salinity and saline water intrusion, and mapping areas likely to be subject to flooding.

In conclusion it became evident from the transport survey that the terrain evaluation and associated mapping derived from the interpretation of remote sensing data could provide a viable basis for monitoring dynamic phenomena within the physical environment. An obvious example in this regard was the use of Landsat imagery to monitor flooding, changes in river course, accretion of new land and changes in land use practice likely to affect transport infrastructure. These possibilities are continuing to be evaluated by the Transport Survey Section of the Bangladesh Planning Commission which was formed and has been functioning since the survey was carried out.

Hong Kong geotechnical studies

At the opposite end of the scale, and in complete contrast to the study outlined above, very detailed investigations have been undertaken in Hong Kong using high altitude aerial photography which is becoming an increasingly used method of remote sensing. In the recently completed harbour reclamations and urban growth project the development potential of reclaimable, redevelopable and under-utilised sites in the 150 sq Km study area had to be assessed as an input to a strategic planning review of the Territory as a whole, taking into account the potential and needs of each of its sub-regions. In undertaking the study, airphoto interpretation was used in the overall requirement to collect, analyse, and present information relating to socio-economic characteristics, land use, housing, employment, hydrographical, geotechnical, geological and environmental data and infrastructure, including transport and communications.

One of the main investigations of interest in this programme concerned the use of airphoto interpretation and terrain evaluation in the evaluation of sources of suitable fill material. At the outset, the Geotechnical Control Office of the Hong Kong Government provided a draft version of their geotechnical area study reports on the selected region of interest, which included very detailed terrain evaluation mapping, with each facet coded to identify geology, slope angle, land use, geomorphological characteristics and any special features of geotechnical interest; e.g. old landslip. On the basis of these data the Control Office had been able to produce derivative maps including a series referred to as geotechnical land use maps. The study team were thus able to use these maps in conjunction with airphoto interpretation and requantify the geotechnical attributes to produce a borrow utilization map which ranged with subdivisions from Class 1 : flat land on granites, good for borrow to Class 3 : steep hillslopes on volcanic rocks, poor for borrow. On the basis of this study, a provisional borrow map was generated after boundaries had been adjusted on conclusion of airphoto and ground survey checks, and quantities of different types of borrow estimated from the original terrain mapping (SWK, 1983). Although various problems were encountered, airphoto interpretation proved invaluable in detailed estimates of the ratio of soft and rock fill quantities and depth of overburden to bedrock at specific sites, even though a good correlation was not obtained for depth to bedrock with individual terrain units.

Other successful uses of high altitude aerial photography and terrain evaluation in Hong Kong have mainly concerned land development and problems of slope failure. Geotechnical land use planning is particularly important in the Territory where rugged weathered topography and a still rapidly expanding population create severe pressure on the limited amount of suitable building land. As part of the government's overall strategy of decentralisation, steady progress has been maintained with the development of three new towns, each capable of housing about 500,000 people. The core of one of these towns, Tuen Mun, is located in a valley flanked by steep hill ranges up to 500m high. This difficult topography has resulted in land for the town having to be reclaimed from the sea, the fill being obtained from borrow areas in the adjacent hillsides. Apart from foundation and settlement problems associated with multi-storey building construction on new deep reclamation, geotechnical problems also arose from the development of borrow areas themselves. A particular aspect of concern at these sites was the likelihood of slope failures occurring in colluvium overlying weak, deeply weathered residual soils.

In the geotechnical and engineering geology site investigations a terrain evaluation study was undertaken based on airphoto interpretation. This proved successful in identifying old landslips and areas susceptible to slope failure, the latter being located through evaluation of landform, geological structure, vegetation, soil moisture and drainage characteristics. Analysis of the airphotos also greatly contributed to an understanding of the mechanisms of slope failure which were attributable to a juxtaposition of different geology and hydrological parameters associated with predominantly permeable granite colluvium overlying an impermeable volcanic residual soil (Hunt, 1982). In addition to greatly assisting problems of potential slope instability, the airphoto interpretation also proved invaluable with respect to the geotechnical terrain evaluation undertaken for purposes of urban development planning. As foundation and slope conditions were fundamental in determining the nature of building which could be carried out within the different areas of the new town, the geotechnical terrain evaluation became an essential part of the planning process and has subsequently formed viable database for infrastructure development and management.

Highway location and design, Malaysia

Landsat satellite imagery and aerial photography have proved effective in various terrain evaluation studies undertaken in Malaysia for highway location and design investigations, and associated agricultural land use surveys required for planning rural access in remote and undeveloped regions. Although problems of dense tropical jungle vegetation can severely limit the useful information which can be determined on landforms and ground conditions in many parts of Malaysia, with the use of the most sophisticated image processing techniques, valuable data may still be obtained on structural geology, hydrology and through relating vegetation characteristics to specific ground conditions. The multispectral nature of Landsat imagery is obviously fundamental to analysing the vegetation canopy and determining unique physical environments on the ground, as for example in the obvious case of mangrove swamps. In the absence of up-to-date topographic maps the identification of surface drainage can be as equally as important on satellite imagery especially with respect to preliminary route location and determination of bridge and drainage structures.

Satellite imagery has also proved useful in Malaysia for identifying areas likely to produce poor foundation conditions. In addition to mapping areas of freshwater and mangrove swamp, peat deposits and similar soil types of weak strength have also been able to be located and avoided through analysis and interpretation of the spectral responses produced by various combinations of soil and vegetation ground cover types recorded by the Landsat sensor system. Similarly, the overall synoptic view provided by Landsat imagery has enabled drainage basins to be studied and geologic structure appraised through fracture trace analysis of interpreted lineaments. On most projects however, and on especially projects undertaken in regions of Sabah and Perak, terrain evaluation studies utilising remote sensing imagery and principally aerial photography, have been reliant on detailed ground surveys in order for viable correlations to be established and extrapolations made to adjacent areas.

The identification of construction materials sources poses many problems in densely vegetated terrain and the interpretation of radar or satellite imagery and aerial photography has only proved effective where sites are located within drainage courses or are associated with recognisable relief features or landforms. On isolated occasions however, it may be possible to locate distinctive vegetation associations on the imagery which can be related to specific soil or rock materials such as laterite. The monitoring capability of Landsat satellite imagery nevertheless is of significant value in densely vegetated tropical regions for studying dynamic phenomena within the physical and social environment. This is particularly relevant to analysis of soil erosion within environmental impact studies of new highways and forest clearance for agricultural and settlement purposes. The future possibilities of using sequential remote sensing imagery from satellite surveillance programmes in conjunction with established terrain evaluation systems of data storage must hold much potential in Malaysia for the prevention of damaging soil erosion, with consequent susceptibility to flooding, and the conservation and management of valuable natural resources.

CONCLUSIONS

Engineering geologists and geotechnical engineers are now able to benefit from the increased availability of imagery forthcoming as a result of rapid technological development and implementation of satellite and aircraft surveillance programmes over Southeast Asia. The use of this information can enable physical terrain surveys to be undertaken rapidly over undeveloped and often remote areas. Moreover, efficiency and accuracy of geological and engineering surveys is able to be significantly improved by integrating the use of remote sensing data in established methods of terrain evaluation and ground survey. As the costs of field work continue to rise, further benefit should be obtained by using these methods to rationalise ground survey and focus effort into the most potentially rewarding areas. In conclusion, it is also anticipated that as engineers and geotechnical specialists become more fully involved in development studies and coordinated planning, the role of radar, satellite imagery, and remote sensing in general, to provide an integrated, multidisciplinary framework for the acquisition, evaluation, storage and extrapolation of information will be greatly appreciated and highly valued.

REFERENCES

AITCHISON, G.D. and GRANT, K., 1968. Terrain evaluation for engineering. *In* Stewart, G.A. (Ed). "*Land Evaluation : Papers of a CSIRO symposium (Canberra)*". Macmillan of Australia, Melbourne, 125-142.

BEAUMONT, T.E., 1979(a). Remote sensing survey techniques. *J. Inst. Highway Engrs.*, 26(4), 2-12.

BEAUMONT, T.E., 1979(b). Remote sensing for the location and mapping of engineering construction materials in developing countries. *Q. Jl. Engng. Geol.*, 12(3), 147-158.

BEAUMONT, T.E., 1980. Remote sensing for route location and the mapping of highway construction materials in developing countries. *Proc. 14th Int. Symp. on Remote Sensing of Environment.*, ERIM, Ann Arbor, Michigan, 1429-1441.

BEAUMONT, T.E., 1984. Interpretation of Landsat satellite imagery for regional planning studies. *In* Kennie, T.J.M. and Matthews, M.C. (Eds), "*Remote Sensing in Civil Engineering*", Blackie, Glasgow, 162-203.

BEAVEN, P.J. and LAWRANCE, C.J., 1973. The application of terrain evaluation to road engineering. *Proc. Conf. on Road Engineering in Asia and Australasia. (Kuala Lumpur, 1973)*, Institution of Engineers and Public Works Department, West Malaysia, 1-7.

BRINK, A.B.A. *et al.* 1966, "*Report of the Working Group on land classification and data storage*". Military Engineering Experimental Establishment, MEXE Report 940, Christchurch, Hants. 97pp.

DFVLR. 1984. "*MOMS-OI, Modular Optoelectronic Multispectral Scanner Experimental Missions on Space Shuttle Flights STS-7 June '83. STS-II (41-b) Feb. '84, Data Catalogue*". (Ed) Hiller, K. German Aerospace Research Establishment (DFVLR), Oberpfaffenhfen, FR Germany, 60pp.

DOWLING, J.W.F. and BEAVEN, P.J., 1969. Terrain evaluation for road engineers in developing countries. *J. Instn. Highway Engnrs.* 16(6), 5-15.

HUNT T., 1982. Slope failures in colluvium overlying weak residual soils in Hong Kong. *Proc. ASCE Geotechnical Engineering Division Speciality Conference on Engineering and Construction in Tropical and Residual Soils. (Honolulu, Hawaii, Jan 11-15, 1982)*. ASCE, New York, 443-462.

LATHAM, J.S. *et al.*, 1983. Monitoring the changing aerial extent of irrigated lands of the Gefara Plain, Libya. *In* Ragan, R.M. and Wolman, G. (Eds), "*Study of Land Transformation Processes from Space and Ground Observations, (Proc. Symposium 10 of COSPAR 24th Plenary Meeting, Ottawa)*," Pergamon Press, Oxford. *Advances in Space Research*, 2(8) 57-68.

LAWRANCE, C.J., 1972. "*Terrain evaluation in West Malaysia, Part 1. Terrain classification and survey methods*". TRRL Report LR506, Department of the Environment, Department of Transport, Crowthorne, Berks. 32pp. (Transport and Road Research Laboratory).

LAWRANCE, C.J., 1977. "*The use of punched cards in the storage and retrieval of engineering information in Ethiopia*". TRRL Report SR248, Department of the Environment, Department of Transport, Crowthorne, Berks. 40pp. (Transport and Road Research Laboratory).

LAWRANCE, C.J., 1978. "*Terrain evaluation in West Malaysia, Part 2. Land systems of South West Malaysia*". TRRL Report SR378, Department of the Environment, Department of Transport, Crowthorne, Berks. 164pp. (Transport and Road Research Laboratory).

MITCHELL, C.W., 1973. "*Terrain evaluation - An Introduction Handbook to the History, Principles and Methods of Practical Terrain Assessment*". Longmans, London, 165pp.

MINTZER, O. *et al.*, 1983. Engineering Applications. *In* Colwell, R.N. and Estes, J.E. (Eds), "*Manual of Remote Sensing, Vol 2 (2nd edn.)*". American Society of Photogrammetry, Falls Church, Virginia, 1955-2109.

NATIONAL ACADEMY OF SCIENCES, 1977. "*Resource Sensing from Space : Prospects for Developing Countries*". National Academy of Sciences, Washington, D.C. 202pp.

ORR, D.G. and QUICK, J.R., 1971. Construction materials in delta areas. *Photogramm. Engng.*, 37, 337-351.

RAY, R.G. and FISCHER, W.A., 1960. Quantitative photography - a geologic research tool. *Photogramm. Engng.*, 24, 545-549.

SIMONETT, D.S. and DAVIS, R.E., 1983. Image analysis - Active Microwave. *In* Colwell, R.N. and Estes, J.E. (Eds), "*Manual of Remote Sensing, Vol 1 (2nd Edn.)*". American Society of Photogrammetry, Falls Church, Virginia, 1125-1181.

SWK., 1974. "*Bangladesh Transport Survey, Final Report Part 8, Basic Data - The Soils of Bangladesh*". Scott Wilson Kirkpatrick and Partners in association with the Economist Intelligence Unit Ltd. under assignment by Overseas Development Association. Government of the Peoples Republic of Bangladesh. Dhaka, 254pp.

SWK., 1983. "*Harbour Reclamations and Urban Growth Study*". Harbour Area Consultants Final Report, Town Planning Office, Public Works Department, Government of Hong Kong, 2 Vols.

WILLIAMS, R.S. *et al.*, 1983. Geological Applications. *In* Colwell, R.N. and Estes, J.E. (Eds), "*Manual of Remote Sensing, Vol 2 (2nd edn.)*". American Society of Photogrammetry, Falls Church, Virginia, 1667-1953.

Manuscript received 29th November 1984