ECAT: the Earthworks Condition Assessment Technique

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ECAT: the Earthworks Condition Assessment Technique

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EXECUTIVE SUMMARY

ECAT is a system for recording and analysing earthworks along highways, for the purpose of planning earthworks maintenance within a corridor or over an entire network. Earthworks are very difficult to monitor because of difficulties of access, visibility and working safely on steep slopes. ECAT is based upon the production of a pictorial record of the earthworks, analysed in an objective way to produce a summary description of earthworks and problems that are becoming visible. Its advantages are speed, completeness of cover and ability to detect early signs of slope deterioration, so that repairs can be put in hand before an expensive slope failure occurs. The system is most appropriately applied in countries where there exists a regime for carrying out regular maintenance, with a commensurate budget, and whose road network is built in terrain where slope failure is a widespread and persistent problem.

ECAT's pictorial record is produced from two sources: a) aerial photographs taken of the earthworks from a helicopter flying along the route at close range; b) a video-log of the carriageway and surroundings, collected from a car driven along the road with a digital camcorder mounted in the front looking forwards. The results of the analyses are fed into a database which then provides information about the state of the earthworks on the network in response to standardised or specific questions submitted by the engineer. Geographical co-ordinates are included, so the data can be used within a GIS environment. This is a 'high-tech' solution but all the equipment is available on the domestic market, even in developing countries, and is inexpensive in comparison with the cost of repairing, say, one large landslide.

The aerial helicopter survey, the mainstay of the system, provides information at three 'levels', which may be taken as three individual surveys or considered as three stages towards a complete record of the road. The first level is prioritisation of earthworks into those in a bad or failing state that need attention immediately, those where slope degradation is evident but work can be deferred for one or two seasons, and those in which deterioration is minor and no maintenance work will be needed for several seasons. The second level of survey is a complete inventory of the earthworks, used for management and monitoring purposes. The third level is a detailed engineering assessment of selected earthworks (based on photo interpretation), in preparation for remedial work to be designed and undertaken.

During its development ECAT has been used on eleven roads in Colombia, Jordan, Malaysia and Nepal. On the North-South Expressway in West Malaysia it has been incorporated into the maintenance management system by the consultants responsible for the road. Implementation can be either by hiring a consultant to take the photographs and carry out the analysis, or by purchasing the equipment and training a local corps to carry out the surveys and analysis. The second option requires, apart from the investment in equipment and training, commitment by the department (or group of departments in collaboration) to use the system on a regular basis to monitor earthworks and develop a maintenance strategy around the information that ECAT provides.

ECAT has been developed to a point where its technical components have been demonstrated to work both separately and as a system. It does not currently exist as a standardised package ready for release, partly because of constant advances in the capability of electronic devices over the past decade and partly because of the intermittent nature of trials carried out in different countries during that period. Although ECAT has been developed for roads the system would potentially have application for other linear corridors such as railways, pipelines, catchments around reservoirs, and coastlines. Thus, applications could be directed more broadly towards environmental monitoring. The next stage of development would be the consolidation of the system into a standardised package or range of packages with recognisable product identity, aimed at specific markets. An organisation such as TRL, with its understanding of the ECAT system and knowledge of the relevant markets, would be ideally placed to perform such a role.

ECAT: THE EARTHWORKS CONDITION ASSESSMENT TECHNIQUE

1 INTRODUCTION

1.1 Background

ECAT, the Earthworks Condition Assessment Technique, is a system for collecting information about the condition of earthworks along a route and for using this information to assess of deterioration now and in future. The main novel feature of the system is that the initial data collection survey is done by taking low-level oblique photographs of the earthworks from a helicopter. The purpose of ECAT is to assist the engineer to gauge the relative severity of deterioration of an individual earthwork (its 'condition') and of all earthworks on a road alignment or within a network, and thereby to set priorities for repair. An 'earthwork' is defined as any modification made to the terrain to accommodate a bench for a highway. Earthworks are most obviously cut slopes, fill slopes and embankments, but they also include all the associated engineering structures such as drainage systems, walls, culverts etc.

This report describes the ECAT system in terms of its structure, components, general operation, applications and potential for integration into highway maintenance organisations in developing countries. It forms the final report to a Knowledge and Research project funded by the Department for International Development (Structured highway earthworks maintenance, R 6893).

ECAT was devised in order to help engineers in developing countries overcome the difficulties of maintaining earthworks on highway networks. Slope deterioration and slope failure on earthworks in developing countries is often severe, especially in regions combining high and steep slopes with a wet climate. In countries where failures are many, the maintenance of earthworks presents a major problem for engineers because, for various reasons, repairs are carried out after failure has taken place. When this happens, traffic flow is slowed or blocked. Remedial works then become a matter of urgency and resources have to be made available immediately to carry them out.

This situation is highly unsatisfactory for several reasons. First, the failed slope presents a hazard to traffic and road users. Second, the cost of repairs to a slope once it has failed is likely to be much higher than the cost of preventive maintenance carried out over several seasons. Third, repairs are always urgent, which is unsatisfactory from an engineering as well as an economic and planning point of view. Fourth, the situation makes it appear that the Roads Department has failed in its duty: the public may demand to know why the slope failure could not have been prevented.

The reasons why earthworks are not regularly maintained at present are:

- earthwork slopes cover a much larger area than that of the road pavement, which means that there is much more ground to inspect;
- access to the slope is difficult:
    - the slope is often steep;

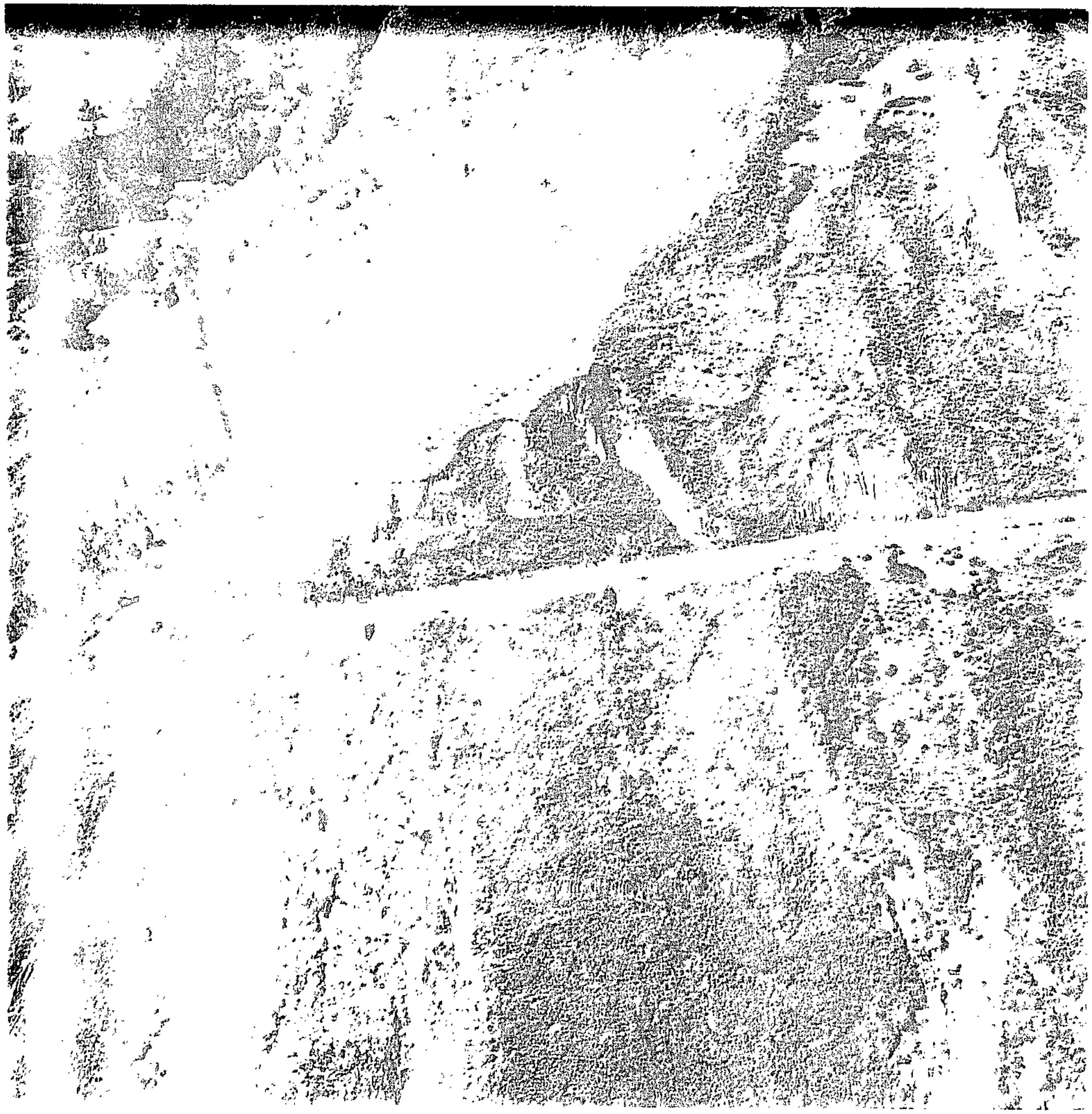


Figure 1.1 Aerial photograph of road traversing hill slope, showing instability above and below road bench

    - vegetation makes movement on the slope physically difficult and obscures the view of the slope;
    - earthwork slopes rarely have built pathways or access routes.
- engineering geological expertise is needed for analysis of the problems but is often not readily available;
- funding for earthworks maintenance is usually not streamed over a number of years, and is rarely sufficient;
- a methodology for categorising and analysing earthwork problems is not available, i.e., an earthworks management system does not exist.

The basic problem is that the engineer does not have an easy means of identifying slopes that are in imminent danger of failing or that are evolving towards failure. After construction, an earthwork slope, if left unattended, may begin to deteriorate. Usually there will be some outward sign of this, such as loss of vegetation, erosion, or disruption of the slope drainage system. These symptoms will get worse as the seasons go by until a major failure occurs, perhaps during an unusually heavy storm. The deposition of material onto the carriageway is often the first indication to the engineer that the slope is failing, by which time it is too late and major rehabilitation is required. Furthermore, if slopes are not maintained until they fail, it must be expected that the number of major failures will increase with time, as more and more cuttings deteriorate to the point of failure. Therefore the costs of repairs will tend to continually rise in real terms.

Note that earthworks failure affects not only the road and road users, it also affects the environment and the whole community. The environment constitutes the hillside catchment upon which the road is built, from watershed to stream course. Delays to the movement of goods and people (even if not in physical danger from the failure) adversely affects business. These delays also affect the local communities served by the roads. Thus, there is a powerful need for a monitoring system that can reduce a) the economic costs of earthwork repairs, b) the danger to the travelling public that earthwork failures represent, and c) the adverse effects that they have upon the environment and rural life.

The engineer's problem in assessing slope condition actually has five aspects:

a. Because of the steepness of the slope and the cover of vegetation the view of the slope from the road is obscured, therefore signs of damage often cannot be seen, especially early on when the signs are small;
b. the engineer has no ready means of describing the state of deterioration (the condition) of slopes;
c. the engineer has no means of separating slopes that most need attention from those that can be left for the time being or require only monitoring;
d. even if it were possible to describe and set priorities for slope maintenance, it is impracticable to examine all slopes on a regular basis with the normal resources of a road inspection party;
e. engineers generally do not have the time or the expertise to offer effective solutions to problems that are essentially of a geotechnical nature. Such problems may be many, and varied.

ECAT was devised to address these problems. Its main idea is that if earthworks failures can be reasonably easily identified and categorised, then the difficulties associated with planning and budgeting for a maintenance programme should be eased. The very high cost of remedial works to earthworks, especially of emergency maintenance, should also be reduced. The value of ECAT is based on the premise that if signs of deterioration can be detected as soon as they start, repairs can be carried out that will prevent or greatly retard further deterioration.

ECAT is designed to work in situations where:

1. The facility is linear in form, such as a road, and where the maintenance organisation has little interest in features far from the alignment or that are not directly related to the alignment. (Networks can be accommodated because they remain linear in concept, i.e., a series of connected lines. However, in situations where features are related more to areas than lines, GIS and spatial analysis techniques become more appropriate).
2. The features of interest are visible at the surface, and of such a nature as to be seen well from the air but not from the ground (e.g., rills on road cuttings).
3. The geological environment is very active and the slope morphology tends to change markedly every year. This situation necessitates constant monitoring.
4. In cases where a video-log (the ground-based component of ECAT) is appropriate, access along the facility must be fast and easy, in order to make the recording of the video-log cost-effective.

1.2 The requirement for earthworks maintenance management

The scale of earthworks on the world's highways has increased considerably in the last thirty or so years; there are more roads, more roads are being built in steep terrain, and road geometry has improved, increasing the size of the earthworks. Thus, the overall level of risk from earthwork failure is increasing.

The traditional way of dealing with an earthworks problem is to carry out an engineering geological ground investigation (after failure has occurred). This is still the most accurate method but it is slow, expensive, specific to the site and requires specialised expertise. Earthworks deterioration is, by nature, widespread, gradual, patchy and diverse. A monitoring system is required that enables engineers to identify problems early and decide how best to deal with them. Early signs of deterioration (e.g., erosion) can be identified without necessarily the need for a high level of analytical expertise. In road pavement management, an overseer and patching gang can deal with minor superficial problems and keep the road in good condition. In reporting these to the engineer, pavement monitoring is effected.

Maintenance management depends as much upon institutional factors for success as upon a practicable methodology. In earthworks maintenance, the institutional factors that hamper effective pavement maintenance are present in greater degree by the nature of the problem as outlined above. The engineer's problem of earthwork maintenance is exacerbated by the lack of any systematic methodology for managing an earthworks maintenance programme.

ECAT in its present form does not include maintenance management routines, but the system is amenable to operation within a maintenance management environment, of which ECAT itself could form the core. While the principles of maintenance management would no doubt apply to ECAT in the same way as for a pavement management system, the attributes measured, the means of measurement, the frequency of measurement and the thresholds applied would be specific to an earthworks environment. For the present, ECAT represents a means by which the problems of earthwork monitoring can be solved. For the future, ECAT constitutes a tool around which an earthworks maintenance management system can be developed.

The requirement is for a methodology that encompasses:

1. Monitoring methodology:
   - a rapid and easily-repeatable survey method;
   - recording and description of sites;
   - location of sites so that they can be identified on databases and in the field.
2. Classification of:
   - failure types;
   - failure progression:
     - type of deterioration;
     - rate of deterioration;
   - severity of a failure (hazard and risk);
3. Strategy for setting priorities and planning repairs, for a whole road or network.

ECAT addresses the five engineering problems noted above in the following ways:

1. *Slope cannot be seen clearly.*
   ECAT makes use of large scale oblique aerial photography to provide a clear view of the earthworks and surrounding ground.
2. *Slope condition cannot conveniently be described.*
   ECAT incorporates a pro-forma system for recording data about the earthworks in a systematic, relatively consistent and easy-to-apply way.
3. *There is no means of allocating priorities for repair.*
   As standard, there is a procedure within ECAT that allocates a priority rating for repair to every earthwork.
4. *Slopes cannot be examined regularly.*
   The data from the pro-formas are stored in a database. This a) enables any characteristics of the earthworks population to be analysed, and b) enables comparison to be made of the condition of earthworks in different years, i.e., the deterioration of earthworks from season to season can be monitored.
5. *Engineers have neither the time nor the expertise to devise solutions peculiar to earthwork problems.*
   The pro-forma recording system, while geotechnically based, does not require advanced geotechnical expertise to fill in. The maps, data and images held within ECAT provide an overview of the corridor within the office, that can be used by engineers, in collaboration with specialists if necessary, to formulate a plan of action and appropriate designs of remedial works.

To accomplish this ECAT contains:

a. A methodology for describing earthworks systematically, comprehensively and consistently, using aerial photographs and pro-forma descriptions;
b. A database, to store the descriptions of all the earthworks on a highway or whole network;
c. A procedure for analysing the information in the database and producing reports on:
   - priorities for repair for a series of earthworks;
   - engineering assessments of individual earthworks;
   - *ad hoc* queries.

ECAT operations are based upon three stages of activity:

1. Identify signs of deterioration in the earthworks on a road or network.
2. Assess the cause of the problem, and the likely consequences if the situation is left unchecked (i.e., assess the level of hazard and risk).
3. Devise a repair strategy for all the earthworks taking into account the number and severity of the problems and the available budget.

2 ECAT OVERVIEW

2.1 General

ECAT provides a pragmatic solution to the difficulties of earthwork maintenance management. It focuses on ease and speed of data acquisition and ease, speed and consistency of data analysis. At the expense of accurate, detailed information about individual sites (the traditional approach) it takes advantage of the information available from a large amount of more generalised data about a whole road alignment or network, from which to derive a strategy for earthworks maintenance. Supplementary data can be collected from the field but the primary source of information is air photo interpretation.

ECAT has been designed as a system that can be used in a number of configurations to suit the resources, capabilities and requirements of its host organisation. These are summarised as follows:

- its primary intended user organisation is a highway authority in a developing country, but it can be used by a consultancy or organisation such as TRL to provide a service to highway authorities;
- its primary intended users are engineers, but it can be used (and, for design considerations, is probably more appropriately used) by a specialist such as a geologist, engineering geologist, hydrologist or bio-engineer.
- it can be used in a simple way to provide information about the condition of the earthworks on a road or network - this is its overall operational status at present. However, it is capable of being developed into a system that can assist strategic decision-making about earthworks maintenance, and could even be upgraded into a full earthworks maintenance management system;
- it can be used for earthworks alone, but in addition it can be used to show (via its video-log of the route as seen from a vehicle) the general condition of the carriageway, the verges and shoulders, the road furniture and other features occurring along the side of the road, e.g., a dangerous bend or dwellings encroaching too near the road;
- the physical system, in its normal configuration, comprises components that are easy to obtain and straightforward to operate. These are normal office stationery, a desktop computer, scanner, printer and standard database and word processing software. However, in addition it can incorporate or interface with mapping software packages or GIS to provide the capability to generate maps of the earthworks on a route or network, or introduce the capacity for spatial queries regarding earthworks condition.

2.1.1 Hazard and risk

The gradual decline of an earthwork's condition towards slope failure, and the effects upon man, is generally considered in terms of hazard and risk. 'Hazard' defines the attributes of an instability event - its type, mechanism, dimensions and probability of occurrence within a specified time (e.g., the design life of the road). Hazard concerns those components of the analysis that are influenced by the earth sciences. 'Risk' defines the consequences of such an occurrence - the economic value of property or structures at risk, safety issues (risk to life), political consequences or the consequences of failure as it may affect engineered structures (Fookes, 1987)[1].

Hazard is very difficult to quantify, and because of this analysis is often limited to a semi-quantitative assessment or is expressed as relative hazard only. With regard to hazard, ECAT confines itself at present to a relative assessment of hazard, though it makes use of a method that enables a comparison of relative hazard to be made across projects, i.e., a high degree of objectivity is maintained in the hazard assessment. Hazard assessment is formally employed in Level 1 and Level 2 analysis (see Section 3.3). ECAT also addresses risk, in a subjective way. When a calculation is made of a 'priority' rating for a slope, the effect of slope failure upon the road or property is taken into account.

Typical deterioration characteristics that can be identified from aerial photographs are given in Table 2.1. This list is kept under review for modification.

[1] The above definitions have been used consistently in the ECAT project since its inception in 1989. However, more recently it has become generally accepted in the engineering profession to define hazard as a situation that has the potential to do harm or cause a loss, and risk as a combination of the likelihood that a particular hazard will occur and its economic and actual consequences.

Table 2.1 Slope deterioration characteristics used in ECAT
(From McKinnon and Heath, 1996)

Design	1. Slope section constructed to an oversteep angle. 2. Road-bench in very steep hillside. 3. Toe cut oversteep. 4. Inadequate drainage on slopes. 5. Inadequate road-side drains.
Deterioration	1. Oversteep upper section from loss at toe. 2. Splash /erosion from traffic undercuts toe. 3. River erosion at base. 4. Deep hillside gullies discharging onto road.
General	1. Degrading natural vegetation cover on slopes. 2. Large rainfall catchment discharging onto slope. 3. Natural gullies becoming large. 4. End-tipping of debris over embankments. 5. Unravelling on folded/fractured slopes. 6. Non-contained flow off road and embankment erosion. 7. Splash erosion of slopes on flooded road sections.
Road work	1. Road widening resulting in steep toe sections. 2. Installation of drains leaving toe oversteep. 3. End-tipping causing erosion and vegetation loss.
Communities	1. Agricultural area discharge onto earthworks. 2. De-forestation of slopes and infiltration. 3. Poor waste water management in ribbon development. 4. Construction on road slopes. 5. Quarrying material above road slopes. 6. Drain system damage from off-road traffic. 7. Top-loading of slopes due to stock-piling.
River	1. Cutting into toe of embankment. 2. Over-topping road when in flood. 3. River bed rise from sedimentation. 4. Slide blocking river and causing flooding.
Potential landslides	1. By river eroding toe. 2. Slope vulnerable to heavy rainfall, ie poor protection. 3. Left over effect of construction disturbance. 4. Oversteep upper slopes. 5. Ancient slides that might re-activate. 6. Signs of creep and hummocky ground.
Rockfall	1. Plucking of rock and boulders. 2. Excessive blasting during construction. 3. Loose debris above the road. 4. Poor angle of rock bedding. 5. Areas of weak foliated rock.
Embankments	1. Poor toe support. 2. Oversteep embankment section. 3. Culvert discharge erosion. 4. Subsidence due to foundation collapse. 5. Poor compaction resulting in subsidence. 6. River scour. 7. River turbulence or other flow characteristic causing erosion.

2.1.2 Earthwork identification – the 'sector'

A labelling system is used that takes account of the fact that earthworks are objects whose disposition in relation to the road varies considerably. They vary in length along the road – some are very long, others are very short. Some alignments contain almost continuous juxtaposed earthworks, others contain only a few, widely separated. Earthworks may be formed only on one side of the road or on both sides.

The system devised to label earthworks breaks the road into *sectors* along its length, each sector comprising about 250m of alignment. If the road contains a string of large, well-marked earthworks (e.g., cuttings), each will be allocated a sector number. If the road contains a sequence of short cuttings or earthworks on both sides, then several earthworks may fall within one sector and each individual earthwork is given a suffix A, B, C etc. Thus, cut slope above road, 285A; fill slope below road, 285B.

A sector corresponds, more or less, to a single aerial photograph. However, a large earthwork may fall onto two photographs. Conversely, a single photograph may cover more than one sector. If a section of road has no earthworks, the alignment is labelled in sectors 250m in length. Where an earthwork appears in more than one photograph it is given only one sector number. The sector labelling system can be accommodated in the video-log.

2.2 ECAT main components

ECAT comprises four main operational components:

- Inputs: data collection and accession procedures;
- System components: data storage and physical components;
- Actions: database query procedures and data analysis;
- Outputs: reports.

The relations between these components are given in Figures 2.1 and 2.2. The components are described fully in the Chapter 3.

2.3 Functional modes of ECAT

ECAT is modular and therefore of flexible configuration, to meet the aims set out in Section 2.1. The system is designed around three 'levels' of operation, starting at a simple level and building up to a more complex application. These three primary functions are summarised in Table 2.2, together with the secondary modes of operation. The primary functions are the three 'levels' of operation, relating to the amount of detail sought:

Table 2.2 Functional modes of ECAT

Mode	Method and purpose	Output
Level 1 analysis Earthworks categorised by priority for repair	Earthworks placed into categories by hazard and risk criteria, to set priority categories A, B, C	List of earthworks, categorised by priority A, B, C
Level 2 analysis Earthworks inventory	Database of earthworks characteristics, for earthworks monitoring and management	List of earthworks, with their attributes
Level 3 analysis Engineering appraisal	Detailed appraisal of individual sites, to give proposed actions for repair	Report
Ad hoc query	Database query, to supply statistics on earthworks characteristics	Printed lists, tables or graphs
Pavement and verge assessment	Video log from vehicle, to provide inventory, location and visual assessment of the condition of the pavement, verges, road furniture and other roadside features	Video film (the 'video-log') and report
Sketch maps and diagrams	Graphics software, to illustrate outputs	Printed diagrams
Maps of earthworks	Link to mapping package or GIS, to show distribution of earthworks along road	Planimetrically accurate maps

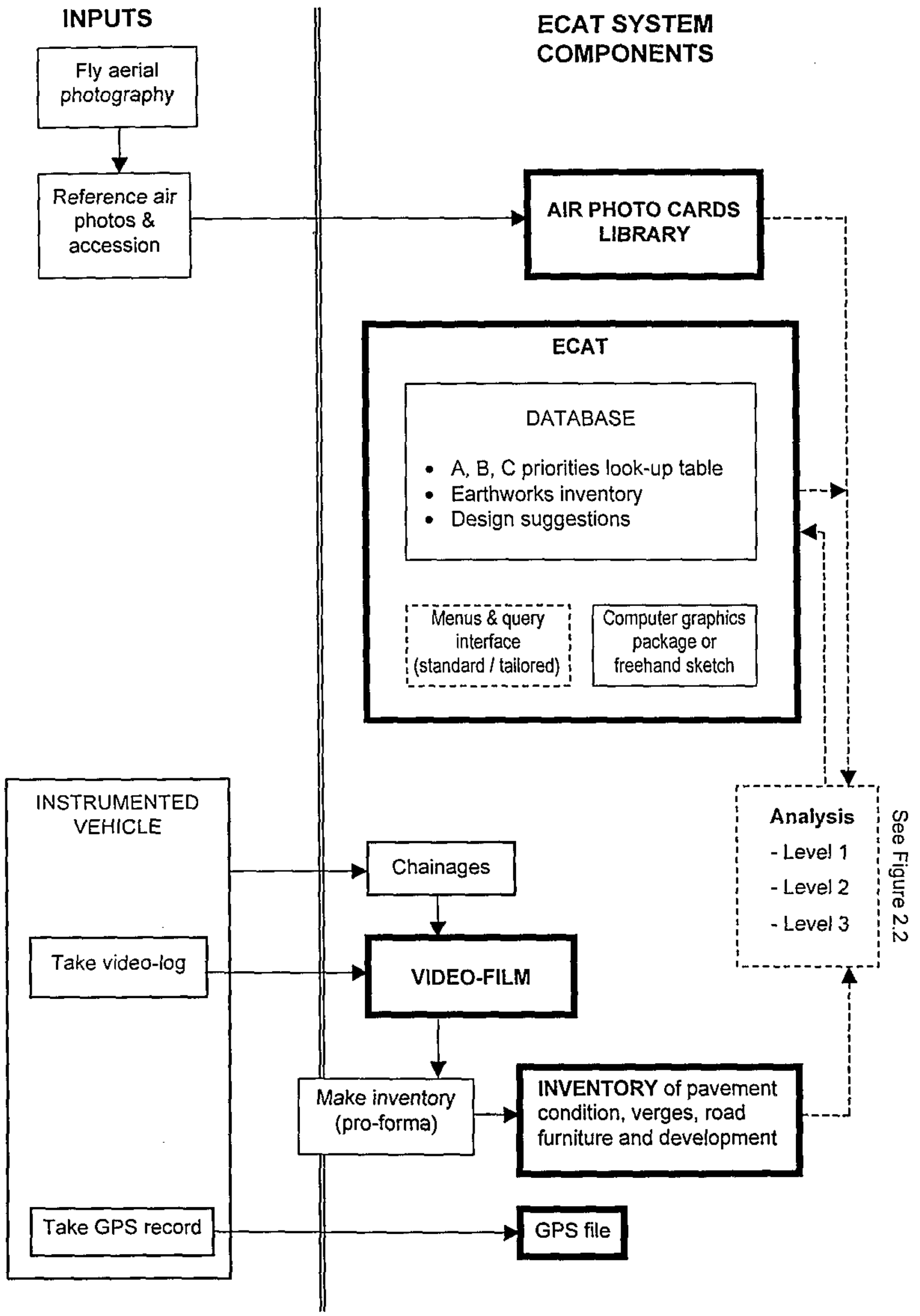


Figure 2.1 ECAT inputs and system components

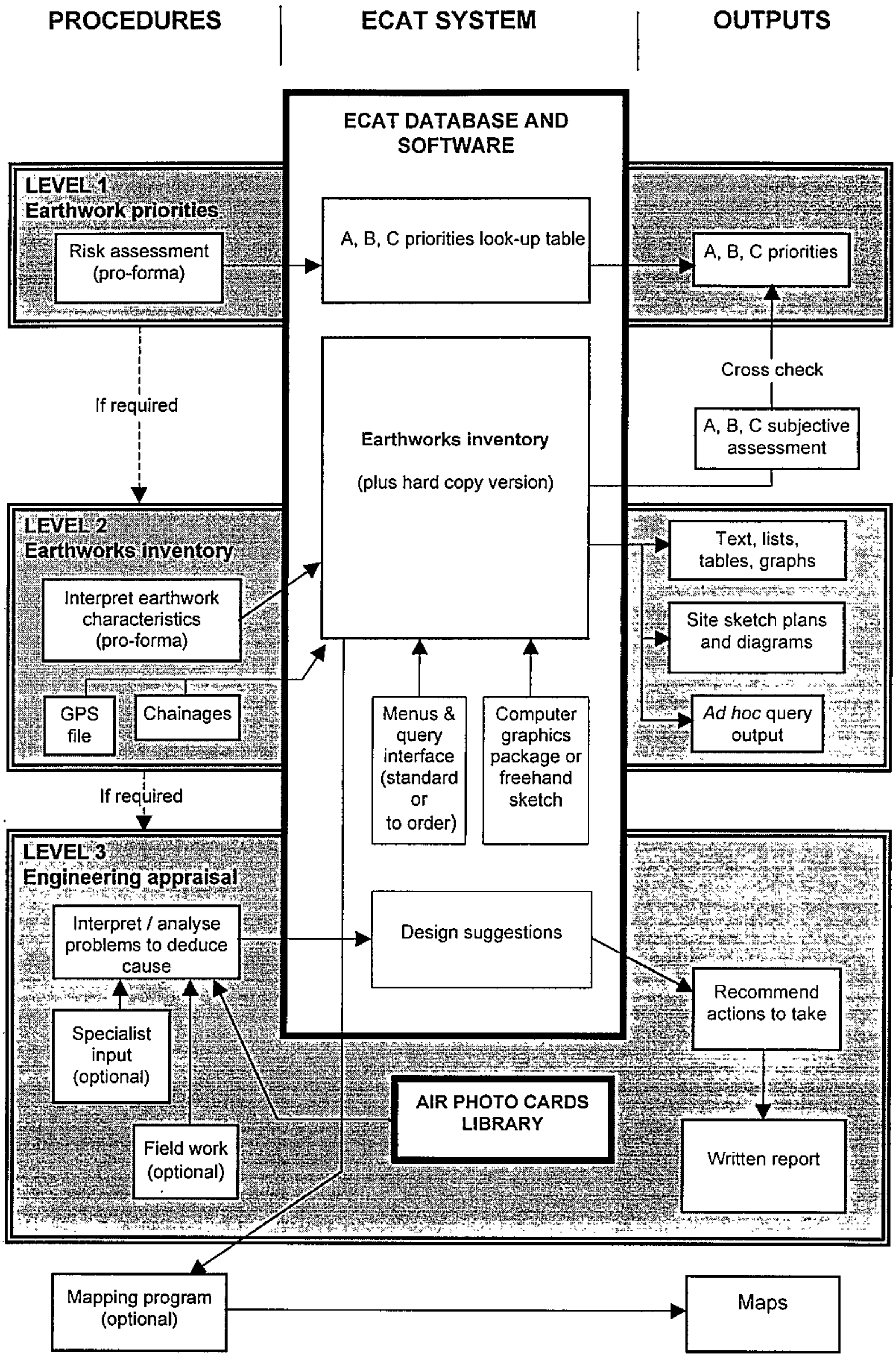


Figure 2.2 ECAT procedures and outputs

The phases are described as 'levels' because each can be undertaken independently. However, it is envisaged that, normally, the three levels would follow one upon the other, as evaluation progresses from initial categorisation through to implementation. Thus, they might equally well be considered as 'stages' in a continuing process, as they have been referred to in publications on ECAT to date.

2.3.1 Level 1 analysis

Level 1 operation is concerned with an initial categorisation of earthwork problems and the general condition of the road. This involves making an assessment of how bad the problems are and where they occur. It involves categorising the earthworks into three categories, depending upon their urgency for repair.

Category A: High priority. Earthworks in a fragile state or where slope failure is imminent, or where the level of risk is high. Remedial works are required immediately (before the next rainy season).

Category B: Medium priority. Earthworks are showing signs of deterioration and should be attended to within the next two or three seasons.

Category C: Low priority. Earthworks showing no deterioration, or which can safely be left for several seasons before repairs need to be considered.

Determination of these categories for each earthwork is done in a two-stage process. First, from an examination of the aerial photograph of the earthwork the interpreter assesses the condition of the slope and gives it a severity rating under the heading of five risk categories (Table 2.3). The degree of risk runs from 1 (least serious) to 5 (most serious). Second, the assessment is entered onto a pro-forma and the values for the first four attributes transferred into a database. A look-up function is applied to the matrix of assessments (625 possible combinations) to arrive at an overall assessment of risk, and hence priority for repair. Figure 2.3 gives an example of risk scores.

Table 2.3 Risk ratings applied to earthworks

Grade	5	4	3	2	1
Risk category					
Degree of danger to road users	Definite danger	Probable danger	Possible danger	Little danger	No danger
Likelihood of the slope to fail	Failure imminent	Potential failure	Possible failure	Low likelihood of failure	No failure likely
Delay to road users	Days	One day	One hour	Minutes	None
Scale (cost) of repair	Realign road	Reconstruct road	Major repairs	Minor repairs	None
Long term prospect of failure (several years)	*Not used in risk prioritisation*				

Figure 2.3 List of criteria for 'A' sector earthworks, Bogota - Villavicencio road, Colombia

Sector	Km	Hazard	Failure	Road loss	Repair cost	Long term	Overall score
13	22.500	5	4	5	3	5	7
17	24.300	4	4	4	5	5	8
18	24.500	4	4	4	4	5	8
19	24.900	4	4	4	4	4	8
20	25.300	5	4	3	3	4	7
21	25.500	4	5	5	5	5	9
26	27.800	4	5	5	5	5	9
28	29.000	4	5	5	4	5	9
29	29.300	4	4	4	4	4	8
35	32.150	4	4	4	4	4	8
38	32.600	5	5	4	4	5	10
40	33.450	4	4	3	4	4	7
45	34.950	5	5	4	5	5	10
46	35.250	4	5	5	5	5	9
47	35.600	5	5	5	5	5	10
48	35.850	5	5	5	5	5	10
49	36.100	5	5	4	5	5	10
50	36.300	4	4	4	4	4	8
etc							

2.3.2 Level 2 analysis

Level 2 comprises a complete description of each earthwork – an earthworks inventory. It concerns the maintenance planning stage, in which more detailed information is required about the cause and extent of deterioration of each earthwork. The characteristics in the inventory describe the features of the earthworks, rather than their forms of deterioration as emphasised in Level 1. Compiling the inventory takes much longer than Level 1 categorisation because of the large number of earthwork characteristics to be identified and encoded (about 60). However, the inventory forms the main reference component of ECAT; it becomes the database and source of reference for all subsequent queries about the earthworks population.

The purposes of the earthwork inventory (database) are to:

- provide a description of the earthworks to which *ad hoc* queries about earthworks can be addressed;
- form a storage system for earthworks condition data. This is used in the development of engineering designs appropriate for earthworks of a particular type and to compare the performance of remedial measures or design strategies over a number of years, in order to develop appropriate maintenance strategies.

The sixty attributes used to describe earthworks are listed in Table 2.4. As before, the engineer observes or interprets the attributes of each earthwork by examination of the aerial photographs, and records them on a data input form. The attributes are then entered into the computer database. The attributes form is given in Appendix 1.

Table 2.4 Characteristics used to describe earthworks
(From McKinnon and Heath, 1996)

LOCATION						
Sector No.	Location	Grid Northings	Grid Eastings	Elevation	Photo No	
Air Photo Scale	Photo Reference	Slope Height	Sector Length	Slope Gradient		
SLOPES						
Type	Shape	Is it on a Bend	Failure Type	Vegetation Cover	Above Slope	
Catchment Size	Inflow to Slope	Geology	Rock Structure	Rockfall Risk	Condition	
Visual Risk	Cause of Failure	Potential Slides	No of Slides	Repairs		
EMBANKMENT						
Type	Steepness	Height	Cover	River Position	River Incuts	
Condition	Visual Risk	Type Failure	Cause Failure	Repairs		
DRAINAGE						
Natural Drains	Side Chutes	Cut-off Drain	Central Chute	Culvert	Other	
WALLS						
Protection Wall	Support Wall	Catch Wall	Masonry	Gabion	Anchor	Concrete
GENERAL						
State of Road	Road Visiblity	Rural Develop	Bridges	Traffic/Heavy	Traffic/Light	

As part of the compilation process, it is recommended to mentally place each earthwork into categories A, B or C priority for repair. The subjective assessment of risk is compared with the 'calculated' assessment of Level 1 to provide a check on the quality of the Level 1 assessment. (Normally, a Level 1 assessment would already have been carried out as a preliminary to the inventory). If any discrepancies are found, the photographs of the site can be re-assessed for degree of risk, to ensure adequacy and consistency of the risk assessment procedure.

Bogota - Villavicencio EARTHWORKS INVENTORY

LOCATION

District:

Sector number: 76 Location: 45.3 Photo number: 97/2/34

Elevation: 0 Grid Northings: 4.351 Grid Eastings: -73.9 Segment number: 5

Photo Scale 1: 1000 Record date: 27/02/96 Reference Photo: 97/6/13

DIMENSIONS

Height: High Sector length: 300 Slope gradient: 1:1

UPPER SLOPE

Visual risk: 3 Main Slope type: Side slope cutting Cut Slope shape: Long

General condition: Poor Slope Failure: Erosion

Catchment value: 4 Slope on Bend: Twisty Top Inflow: 5 Above slope: Agricultural

No of slides: 4 No of potential slides: Yes Rockfall risk: 1

Slope cover - Natural shrub Geology: Rock structure: None

Main cause of problem: Top water Slope repairs: Needs repair

EMBANKMENT

Embankment type: Side-slope Embankment Steepness: 3 Embankment height: 3

Slope cover - Mixed River position: Far River incutting: No

Embankment condition: Average Embankment visual risk: 2 Reason for failure: Slumped

Main cause of problems: Weak material Embankment repairs: Just repaired

EXISTING ENGINEERING WORK

DRAINS:

Natural channels: No Side chutes: No Top cut-off drain: No

Central chute: No Culvert: Pipe Other drainage systems:

Situation of drains:

WALLS

Walls : Protection: Embankment Walls : Support: Walls : Catch-wall:

Masonry Walls: 2 Gabion Walls : 0 Anchor Walls: 0

ROAD

State of Road: Poor Slope visibility factor: 2

OTHER FEATURES

Rural development: Scattered houses Situation of development: Both

Bridge: 0

Traffic: Heavy vehicles: 0 Traffic: Light vehicles: 1

Figure 2.4 Output list: description of earthwork sector 76, Bogota - Villavicencio road, Colombia

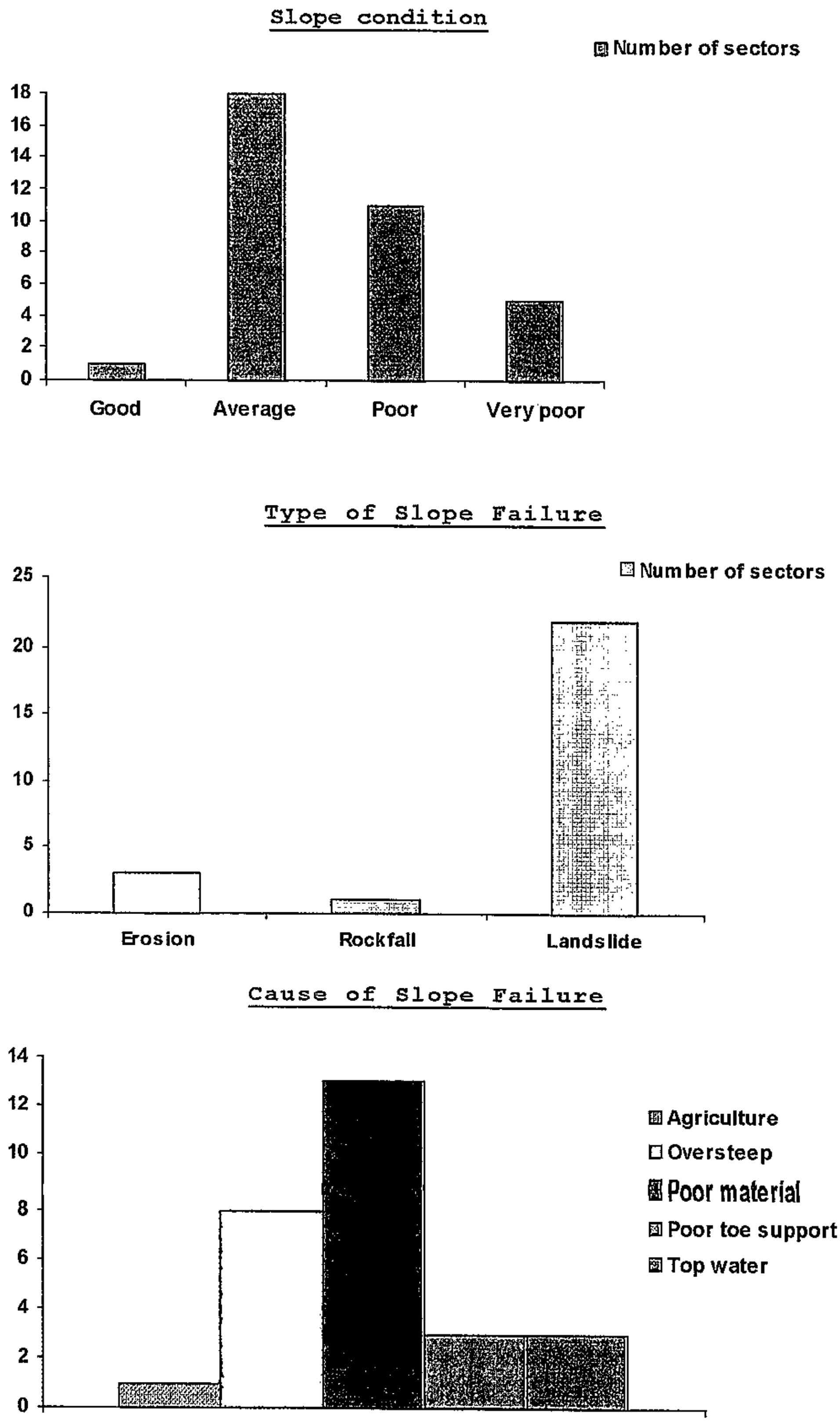


Figure 2.5 Output graph: summary of slope failures, Bogota - Villavicencio road, Colombia

Priority / Sector number	Location	Dimensions H	L	A	Slope: Visual risk	Slope: Type	Slope: Slope Failure	Slope: Catchment value	Slope: Condition	Embankment: Visual risk	Embankment: Steepness	Embankment: Type	Embankment: Condition	Embankment: Reason	State of Road	Rural development
B 76	45.3	High	300	1:1	3	Side slope cutting	Erosion	4	Poor	2	3	Side-slope	Average	Slumped	Poor	Scattered houses
C 77	45.5	Medium	100	.5:1	3	Side slope cutting	Erosion	5	Average	5	5	River slope	Poor	Scoured	Poor	Group of houses
A 78	45.75	High	300	.25:1	4	Side slope cutting	Slide	5	Poor	5	5	River slope	Very poor	Scoured	Poor	Group of houses
A 79	45.95	High	200	0.5:1	4	Side slope cutting	Slide	4	Average	3	4	River slope	Average	None	Average	Group of houses
A 80	46.1	High	200	0.5:1	4	Side slope cutting	None	4	Poor	5	5	River slope	Very poor	Scoured	Average	One house
A 81	46.5	High	200	0.5:1	3	Side slope cutting	Slide	5	Average	2	3	River slope	Good	None	Average	One house
A 82	46.95	Very high	200	0.5:1	5	Side slope cutting	Slide	5	Poor	4	4	River slope	Poor	Scoured	Average	
A 83	47.2	Medium	100	0.5:1	4	Side slope cutting	Slide	3	Poor	4	4	River slope	Poor	Scoured	Average	
C 84	47.6	Medium	200	1:1	3	Double cutting	None	2	Average	2	2	River slope	Average	Collapsed	Average	Group of houses
B 85	48.1	High	200	1:1	4	Side slope cutting	Slide	4	Average	3	2	River slope	Average	Scoured	Poor	Group of houses
B 86	48.3	Very high	300	0.5:1	4	Side slope cutting	Slide	5	Poor	4	3	River slope	Poor	Scoured	Average	Group of houses
A 87	48.65	Medium	200	1:1	4	Side slope cutting	Slide	4	Average	4	5	River slope	Poor	Slumped	Good	Scattered houses
A 88	48.85	Medium	200	1:1	5	Side slope cutting	Slide	4	Poor	3	3	River slope	Average	None	Average	Group of houses
A 89	49	Medium	200	1:1	5	Side slope cutting	Slide	4	Very poor	4	4	River slope	Poor	Scoured	Average	
C 90	49.3	High	300	1:1	3	Side slope cutting	Slide	5	Average	2	3	River slope	Average	None	Good	One house
A 91	50	High	200	0.5:1	5	Side slope cutting	Slide	5	Poor	5	5	River slope	Very poor	Scoured	Average	One house
C 92	50.4	Low	300	3:1	3	Side slope cutting	Erosion	3	Average	2	2	River slope	Average	None	Average	Scattered houses
A 93	50.7	High	200	0.5:1	5	Side slope cutting	Slide	4	Very poor	5	5	River slope	Very poor	Scoured	Average	Scattered houses
A 94	51	High	100	0.5:1	5	Side slope cutting	Slide	5	Very poor	4	3	River slope	Poor	Scoured	Average	

Figure 2.6 Output list: summary of earthworks (part), Bogota - Villavicencio road, Colombia

Outputs from the inventory take the form of lists, tables and graphs, generated as a result of queries to the database. These queries and outputs may follow standard formats (built into ECAT) or can be set by the user. Alternatively, outputs can be transferred to a mapping package (separate from ECAT) and printed as maps. Some typical outputs are shown in Figures 2.4, 2.5 and 2.6.

2.3.3 Level 3 analysis

A Level 3 assessment constitutes a full appraisal of the condition of individual earthworks, in order to make a recommendation for engineering remedial works that are to be carried out. Level 3 concerns the implementation phase. Some earthworks may require a detailed assessment of characteristics such as the rock structure, extent of vegetation, hydrological features, modes of failure etc., so that options for the repair of the slope can be considered. A site plan, outlining the type and location of remedial works, might be among the outputs. This would be used by the engineer as a starting point for the design of slope works.

Level 3 is normally applied only to earthworks rated Priority A because of the amount of work involved. As before, the assessment is made by interpretation of the aerial photographs. Normally, a Level 1 and Level 2 assessment would have been carried out prior to Level 3, but neither need necessarily precede Level 3.

The analysis can be made by the engineer or by any specialist brought in for the purpose. The specialist can be an engineering geologist, hydrologist, bio-engineer or the like, or several experts, whoever are felt necessary to provide a comprehensive assessment upon which to base a decision on appropriate remedial works. The slope condition can be analysed for any or all of the features in Table 2.5, or any other features considered relevant.

Table 2.5 Typical features interpreted in a 'Level 3' engineering assessment
(From McKinnon and Heath, 1996)

Geology	Geological boundaries Rock structure and discontinuities (e.g., joints and faults) Weathered zones
Soils	Depth of soil to rock head Visible characteristics of weathering layer(s)
Geomorphology	Erosion Mass movement features and classification
Hydrology	Surface drainage features Springs and seepage points
Vegetation and land use	Vegetation type Density or continuity of cover Arrangement or distribution of vegetation Agricultural or agro-forestry activity, including grazing

Eighteen forms of failure have been identified, to help the analyst identify features relevant to the failed slope and its repair. These are shown in Table 2.6.

Table 2.6 List of earthwork failure types

Cut slopes	Deep circular slide Shallow circular slide Lack of toe support Avalanche-type slide Surface erosion failure Gully flow failure
Embankment	Embankment toe loss Culvert erosion Embankment collapse Embankment edge failure Pavement cracking Pavement seepage
Slides	Slip landslide failure Creep landslide failure Failure by both slip and creep Ancient slide failure Rock fall Boulder fall

The output from the detailed analysis is a report on the condition of the earthworks and recommendations for remedial measures. It is desirable that a prognosis on the long term stability of the earthwork should also be provided. This will assist future assessments of the earthwork.

3 ECAT COMPONENTS

3.1 Introduction

A catalogue of the essential ECAT components follows, with a brief description of their functions and inter-relations. Refer to the flow diagrams in Figures 2.1 and 2.2 for a general overview. Enhancements are discussed within the descriptions. The components are discussed under:

- Purpose — The reason for the component, and when it is applied;
- Methodology — How the component is operated or put into effect;
- Technical — Technical details relating to the functioning of the component and its application.

The main components are:

1. Data collection
   Helicopter service.
   Hand-held camera and accessories for taking oblique aerial photographs.
   Motor vehicle with video-logging system and GPS (Global Positioning System).
2. Data storage
   File of aerial photographs, one per road corridor.
   Database, running on database software as below.
   Hard copy file of earthwork records constituting an earthworks inventory. (As required, for each route).
3. Data analysis and output
   Proprietary database and graphical software packages running on a personal computer, including printer and scanner. Data are transferred between packages, therefore all must be fully compatible.
   ECAT software, running concurrently on the personal computer.

3.2 Data collection

3.2.1 Aerial photography

Purpose

The aerial photography is the main recording system of ECAT. It is the main source of data on the earthworks, collected by interpretation of the photographs. The photographs are inspected for details of slope condition and interpreted for likely causes and progression of slope deterioration.

Characteristics shown in ECAT aerial photographs are:

- The general slope location with respect to the surrounding ground and the general configuration of the site;
- Engineering and bio-engineering structures present;
- Slope condition – erosion scars, instability features;
- Hydrological features of the earthwork and the slopes above and below. This can include general features of the catchment above the earthwork;
- Rock structures present and slope condition in relation to these;
- Physical characteristics of the soil layer;

- Vegetation type and amount;
- Pavement and roadway features, and damage in relation to the wider site (e.g., erosion below a culvert);
- Human activity on or near a site (e.g., dwellings, irrigation, quarrying etc).

Methodology

The aerial photographs are taken from a helicopter at an oblique angle to provide a detailed face-on view of the earthworks. A continuous strip of photographs is taken as the helicopter flies parallel to the route. The photographer sits in the open doorway aiming the camera towards the slopes, taking as nearly parallel a line of photographs as practicable. In addition, he will use his judgement to take other views of the earthworks during the flight to capture as many aspects of their surface characteristics as possible.

Technical

The photographs are taken at very large scale – ideally about 1:1,500. The basic scale depends upon the size and shape of the earthworks, and is decided on before the flight takes place. The actual scale of each photograph depends upon the ability of the helicopter to get into an optimum position and therefore tends to vary from frame to frame, as does the actual viewing angle. Notes on using a helicopter are given in Appendix 2.

The photographs are taken with a 70mm camera, fitted with a pistol-grip handle with shutter release. The 70mm format gives photographs of high resolution while the camera is compact enough to handle and point at a moving target in an ever-changing scene. A 35mm camera is in all respects cheaper and easier to deploy, but the small lens format does not give a sufficiently high resolution for reliable photo-interpretation. It would be possible to use a camera of a format larger than 70mm but these are bulky and much more expensive to buy and operate.

As well as oblique photographs, a secondary set can be taken vertically. The advantages of these are:

- They show details of the catchment area above the earthworks, which is useful when complex hydrology or upstream erosion are involved;
- The photography generates a plan of the road that may be helpful when sorting and referencing the oblique photographs.

It is difficult to take good quality vertical photographs from a helicopter because:

- Without a proper mounting bracket the camera cannot be held vertical. Mounting a bracket on an aircraft requires aviation authority approval and is strictly controlled;
- It is difficult for a helicopter to maintain a straight and level flight path.

An overlapping run of stereo-pairs, as in normal aerial photography, cannot be obtained.

An optional item of equipment is a hand-held video camera, used to record the whole flight in general. The video footage is useful in identifying the individual aerial photographs in the accessioning process.

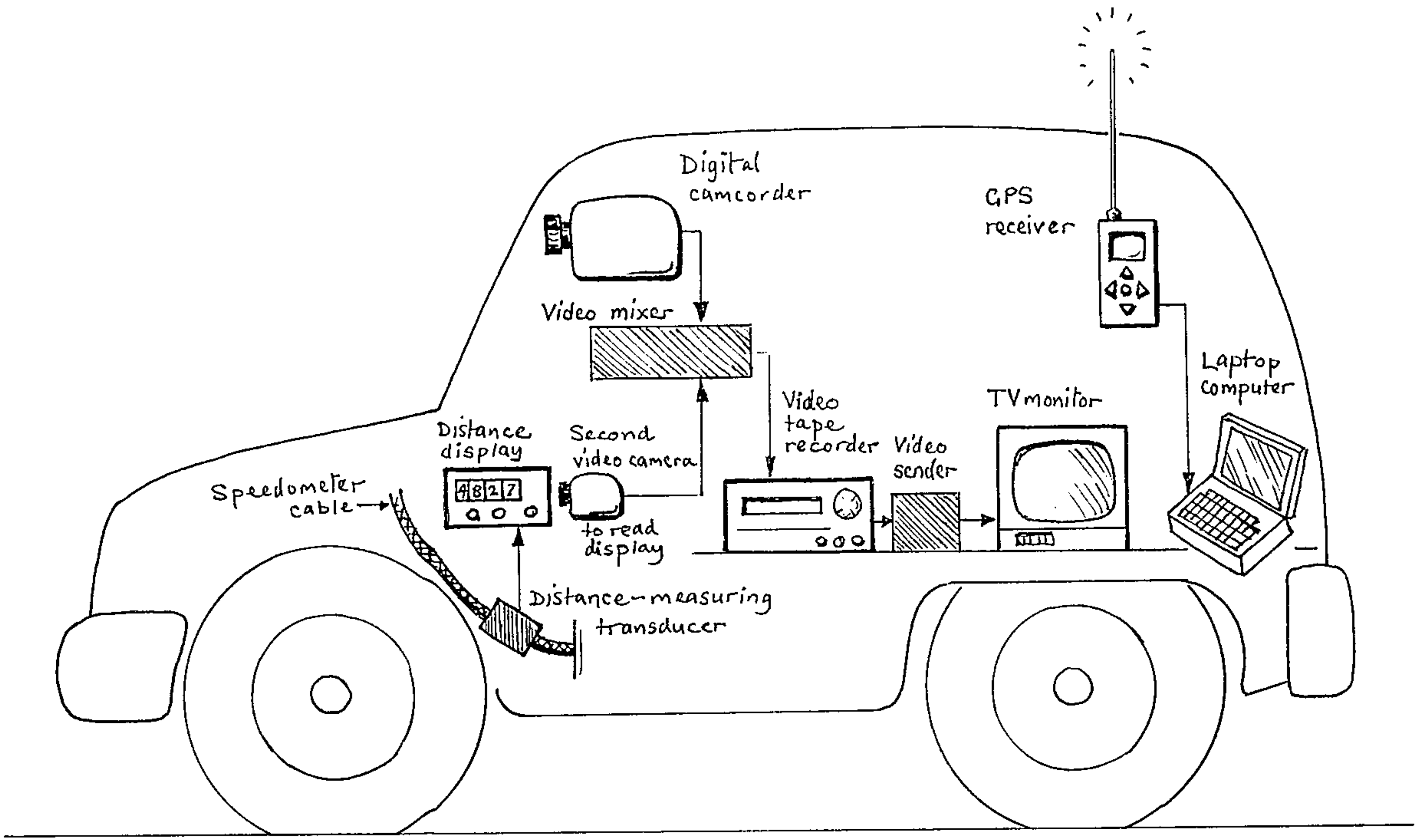


Figure 3.1 Schematic arrangement of video-logging equipment within a vehicle

3.2.2 Video-log

ECAT requires an accurate measure of distance along the road (chainage) in order to give an accurate location for the earthworks. The accuracy with which chainage is recorded on routes in developing countries is highly variable – methods of indicating chainage vary and the figures given are not always reliable. The only satisfactory solution is to make one's own record. The video-log is a technique that has been developed to solve this and other practical problems, as explained below. However, in itself the video-log is not essential to the operation of ECAT as an interpretative technique based on aerial photography. The video-log can be considered an optional extra. It only becomes essential if an assessment and permanent record of the pavement and verges is deemed necessary.

The various items of equipment are described below.

Purpose

The video-log is a video-taped record of the whole route, taken by a camcorder mounted in the front window of a car. It has three purposes:

- To provide a continuous picture of the route, linked to an accurate measure of chainage and geographical position so that the aerial photographs can be correctly ordered and located;
- To generate a plan trace of the alignment;
- To provide a picture of the pavement and verges for visual assessment of condition, if required.

Methodology

The video-log is collected by mounting a camcorder in the front window of a vehicle and then driving the route to take a continuous record of the journey. The video record is linked to a distance meter. Separately, a GPS records the geographical location of the vehicle as it moves along. Thus:

- The video provides a picture of where the car is;
- The distance meter provides an accurate measure of chainage. Chainage is linked to the road by a picture-in-picture display of the chainage within each video frame;
- The GPS gives the geographical position of the vehicle at all times. The geographical position is added to each air photo record, and the GPS record is used to generate a simple map of the route in the form of a line trace.

Technical

Figure 3.1 shows in schematic form how the equipment is deployed in the vehicle.

Digital video camcorder

The camcorder is mounted looking forward in the front of the vehicle to record a picture of the full width of the carriageway and the verges. Thus, the view includes street furniture, barriers, roadside buildings, etc, as well as at least the lower part of the cuttings. The vehicle drives steadily along the road at a speed of up to 50km/hr. A car can be used but a 4WD vehicle is better because it affords a higher viewpoint and is more spacious.

Distance meter
The digital distance meter is connected via a transducer to the vehicle's speedometer cable. (This modification is easily carried out locally). The meter gives a digital and visual readout to the nearest 10 metres along the road. The distance meter also contains a time signal output. This is synchronised with the time on the GPS to provide the link between distance along the road and geographical position.

Secondary video camera
A simple video camera captures the readout of the distance meter and sends it to be mixed with the camcorder's picture of the road.

Video mixer unit
This takes the video signals from the two video cameras and combines them so that the distance travelled appears as a small frame within the view of the road, for every video frame.

Video tape recorder
The VTR takes in the combined image and records it onto tape, for playback on a VTR, professional or domestic.

TV monitor
The TV monitor provides a means of checking that all equipment is working correctly during the data collection run. Its signal is taken from the VTR via a video-sender.

GPS receiver
The Global Positioning System receiver generates a stream of geographical co-ordinates as the vehicle moves along. These are sent directly to the laptop computer because the GPS cannot hold all the co-ordinates of a long route in memory.

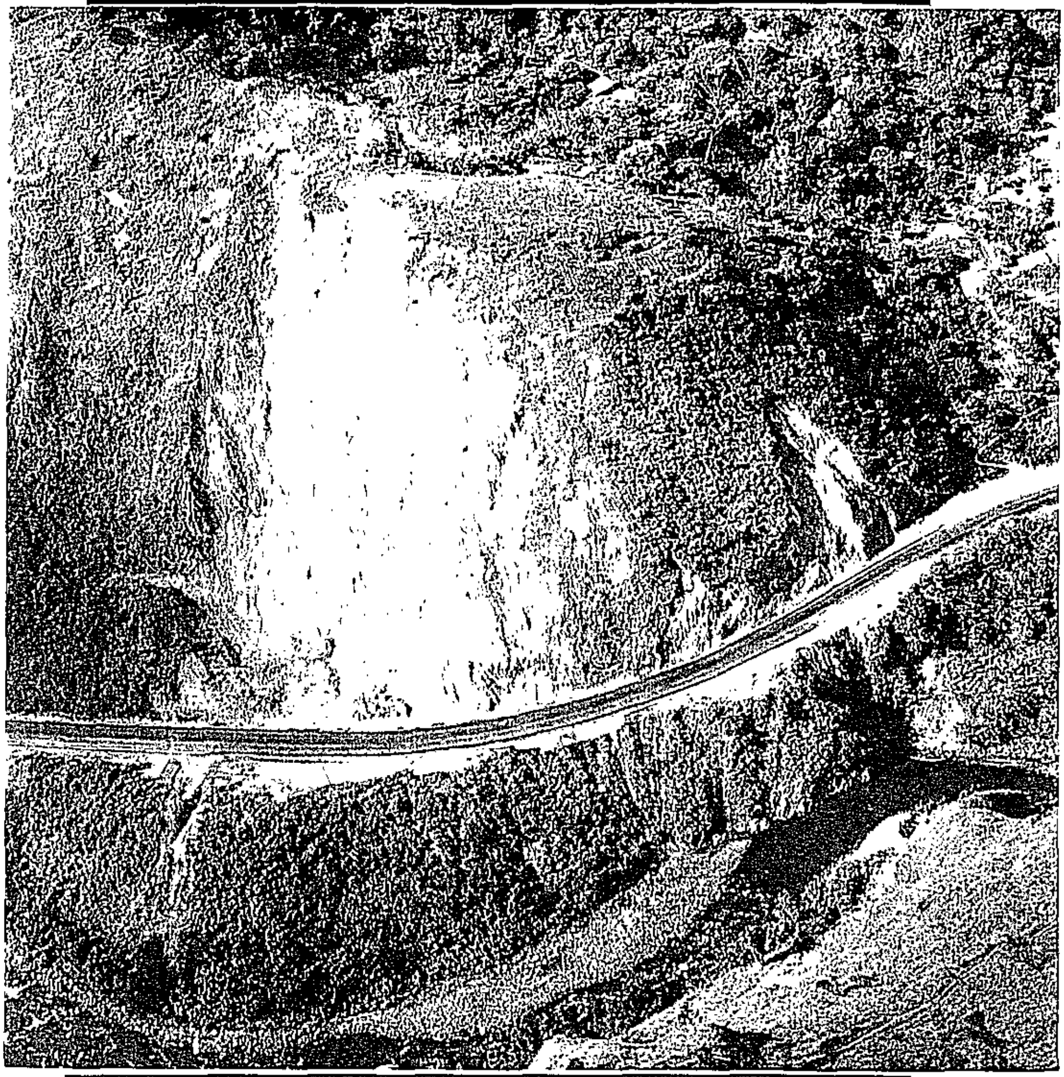
Laptop computer
The computer takes in the data stream from the GPS.

3.3 Data storage, analysis and output

3.3.1 File of aerial photographs
The aerial photographs, once sorted, are stuck onto A4 cards. The cards are pre-printed with a form containing descriptors of the earthwork, ready to be filled in (Figure 3.2). These are then stored in a box file, in order of chainage, as a permanent record of the route. This record is extremely valuable as a medium for demonstrating to engineers, planners and senior staff the condition of the earthworks at one or many points. They also form a convenient means of comparing changes that have taken place in an earthwork photographed on more than one occasion.

BOGOTA to VILLAVICENCIO ROAD

Assessed on 5th Feb 1997



LOCATION INFORMATION

Sector number 93

Location 50·7

Photo number 97/2/58

RELATIVE HAZARD RISK FACTORS

Hazard risk 5
Failure risk 5
Road loss potential 5
Repair complexity 4
Potential deterioration 5

Figure 3.2 Earthwork descriptor card

3.3.2 Personal computer and peripherals

Office equipment required to install ECAT is basic:

- Personal computer capable of running Microsoft Access;
- A4 inkjet printer or equivalent. Colour is optional;
- A4 scanner (optional).

Software:

- Microsoft Access;
- Mapping package, e.g., MapInfo (optional).

3.3.3 ECAT software

The ECAT software comprises:

- A user interface;
- A look-up table, used to allocate a priority rating A, B or C to a set of earthworks in Level 1 analysis;
- 'Help' screens describing geotechnical formulae and designs as suggestions for remedial works;
- Routines for preparing queries to be put to the database. Queries can be standard or to the user's requirement;
- Output routines that produce lists, tables and graphs in standard format or to the user's specification;
- Internal programs accessing the database and a proprietary graphics package.

3.3.4 Mapping package

ECAT in its basic configuration can display as a map only the alignment provided from the GPS output. This can be taken into any professional graphics package and displayed or printed. However, without the facility to edit and annotate it the alignment map is of limited value.

A mapping package, MapInfo has been used to take in the GPS data and add to it the locations of a selected range of sites, to demonstrate how the sites can occur in bunched groups. MapInfo is an optional extra at present. Development of this application towards incorporating it as standard within ECAT beyond the example given has not been undertaken so far.

The facility to draw, annotate and manipulate map data to make good quality maps would be extremely useful. Map data processing could be used to illustrate, for example, the way in which certain types of problem are clustered on a particular stretch of road. This is a very persuasive means of drawing attention to the need for maintenance. Illustrated maps also make outputs more intelligible and attractive.

3.4 Operational status

The operational status of ECAT's many components is variable. Development of technical and operational components has advanced in parallel as practical and political opportunities have permitted. Inevitably, some have progressed further than others - some parts are fully fledged and have been used routinely on several projects, others are still experimental for various reasons. The operational capability of each part is summarised below.

Helicopter service
Fully operational. The helicopter system supplies the needs of ECAT very well, although it is by far the most expensive part of the whole operation. At present there are no practicable alternatives but with experience costs can be kept reasonable. The cost of a helicopter is economic when compared with the benefits to be gained by applying ECAT.

Photographic system
Fully operational. Large-scale hand-held aerial photography is a standard technique, used in the assessment of construction progress, disaster damage, etc. Camera designs and film resolution for taking such photographs are well established.

Video-logging system
Effectively operational. Easily-obtainable standard equipment is employed. Some of the equipment is designed for the domestic market and is therefore inexpensive and easy to use. However, while a practical methodology for collecting a video-log has been devised, in its present form it makes use of a relatively large number of items of equipment that require to be operated with some technical expertise. With improvements in electronic technology, no doubt it will soon be possible to combine some of the components, reducing the overall number. The extent to which hardware refinement becomes worthwhile will depend upon the aspects of highway maintenance for which a video-log is deemed to be useful. The GPS component of the data collection system is fully operational as a separate system.

File of aerial photographs
Fully operational. The information on the photograph cards can be easily modified as the system evolves, or according to the requirements of individual clients.

Personal computer system, standard software and peripherals
Fully operational. Hardware technology is keeping pace with the requirements of users.

ECAT software
a. The user interface and standard graphical outputs are fully operational.
b. The look-up program that determines the priority rating of sites is fully operational.
c. The routines for formulating queries to the database are fully operational.
d. The routines for producing reports are fully operational.
e. The screens that offer advice on geotechnical aspects of design are fully operational, although there might always be pressure to add to these. Note, however, that this area of the package may be removed to avoid users placing too much reliance on the suggested designs without adequate verification.
f. The 'housekeeping' parts of the program are fully operational.

Mapping software
This has been employed on some experimental applications but is not yet an operational part of ECAT.

4 ECAT IMPLEMENTATIONS

4.1 Introduction

This chapter discusses implementations of ECAT envisaged for a Ministry of Works highways department. A suitable environment in which to place ECAT is a function of the organisational and political structure within which it resides, the level of implementation as discussed in this chapter and the nature of the terrain. The first two are closely inter-related. An organisation that would be capable of running ECAT successfully would be one that is reasonably well staffed, and with adequate funds and budgetary flow to operate a road maintenance strategy. An appropriate level of implementation is discussed in Section 5.3.

The terrain would need to have certain characteristics in order to make the adoption of ECAT worthwhile as a method of monitoring:

- Earthworks should comprise a substantial proportion of the length of road alignments; the greater the number and size of the earthworks, the more cost-effective ECAT is likely to be.
- Slopes above and below the road should be long, or not easily accessible.
- The climate and rate of weathering should be such that the slopes are subject to continual and relatively rapid degradation by erosion and slope instability.

This yields a situation in which the road network requires continual monitoring and routine and periodic maintenance. In this situation, early intervention to prevent the slope degradation process reduces the long-term costs of maintenance and minimises danger and overall risk.

4.2 Typical implementations of ECAT

Table 4.1 sets out three 'typical' implementations of ECAT. However, ECAT is a modular system, therefore there is no rule governing what a department should have. The main point to note is that each option offers a considerable enhancement in capability, with a commensurate leap in staff commitment and cost. Note also that the Middle and Top implementations include all that is contained in the Basic level; the higher levels represent a greater degree of involvement, not alternative configurations. Refer to Chapter 3 for a full description of the items mentioned in the table.

The main difference between the Basic implementations and the higher implementations is that in the former there is no capability for the host organisation to carry out its own surveys. Here, the surveys and assessments are carried out by an outside organisation. The client would use ECAT purely as a reference, to gain an indication of the present condition of the earthworks on the road or network photographed (in itself a very valuable body of knowledge). They would use this to consider priorities for repair and to obtain statistical information about the earthworks from the database and express the results in graphical form. Further surveys would have to be done by an outside organisation under contract, as before.

In the Middle implementation illustrated, the organisation's commitment is very much increased. The purchase of the equipment for the air photo and video-log surveys alone represents a capital investment of the order of £10,000 - £20,000 *(check)*. Also, staff would need to be capable of taking the photographs and of interpreting them, for which training and practice would be required. The advantage is that further surveys can be carried out as required; more roads can be surveyed, and existing roads can be monitored periodically.

The interpretation of the aerial photographs, and geological aspects of the video-log, requires geological or engineering geological expertise. It may be possible to train staff within a MOW to do this, but instead it may be far more cost-effective for the department to utilise the services of the national geological survey or the geological department of a local university to provide this service on a consultancy basis.

In the Top implementation, the possibility of linking ECAT with a GIS or maintenance management package is considered. This is very much an optional extra that few departments at present would aspire to, simply because GIS and maintenance management systems linked to earthworks are still rarely used within roads departments. ECAT has been linked to MapInfo (a mapping package) in a trial, but this level of implementation is incompletely researched to date. The obvious advantage of operating within a GIS or mapping environment is that good quality maps can be drawn to supplement the graphical outputs from ECAT. This would aid earthworks maintenance planning. The advantage of a MMS environment is that the costs of maintaining the road pavement and the earthworks could be considered together in budgetary planning.

Table 4.1 Three graded implementations of ECAT

Capability and output required	System requirements or *services provided*[1]	ECAT components implemented	Local staffing	Outcome and applications
A. Basic implementations				
1. ECAT system.	ECAT software and normal office software. Standard PC and peripherals. *Aerial photography, video-log and system set-up carried out by TRL or consultant.* *Training in the use of the system*	1. Office PC running ECAT software and database. 2. Aerial photographs of roads surveyed. 3. Earthworks inventory. (Level 2 survey) 4. Video-log.	MOW highway design engineers and maintenance engineers.	1. Priority classification used to determine maintenance strategy for roads covered. Order of works can be modified by organisation if desired. One-off study; no extra routes possible without re-appointing survey consultant with equipment. 2. Report on priority category 'A' slopes. 3. Report on condition of pavement, verges, road furniture and roadside development. 4. Inventory for use in discussing and planing a maintenance strategy. 5. ECAT used to answer *ad hoc* queries and produce standard outputs as required, for the routes surveyed.
2. Level 1 and Level 2 assessment - priority classification and earthworks inventory (including air photo library).	*Interpretations supplied by consultant and presented in report to the client.*			
3. Level 3 assessment for priority category 'A' slopes.	*Interpretations supplied by consultant and presented in report to the client.*			
B. Middle implementations Basic installation plus:		Same as Basic implementation.		Same as Basic implementation plus:
4. Air photo survey capability.	Survey camera and accessories, and access to helicopter service. Aerial photography and system operation carried out in-house. *Training in the use of the system.*		Staff capable of taking photographs, interpreting earthworks condition and planning remedial works. May require a local photographer as well as an engineer. Probably will also require a local geologist for interpretations, especially for Level 3 engineering assessments.	6. Level 1, 2 and 3 assessments of earthwork condition, for any route. 7. Repeat surveys for periodic monitoring.
5. Video-log survey capability.	Video-log equipment (see Figure 3.1). Fitting of equipment into organisation's own vehicle. Video-log and system operation carried out in-house. *Training in the use of the system.*		MOW highway design engineers and maintenance engineers. May also require a local geologist for interpretations.	8. Collect video-log of any route. 9. Condition survey of pavement and environs, for any route. 10. Plan pavement and local off-road maintenance for any route.
C. Top implementations Basic and Middle installations plus:		Same as Basic implementation, plus:		Same as Basic and Middle implementations plus:
6. Capability to use in conjunction with a mapping software package or GIS environment. AND / OR:	*Integration of ECAT with program.* *Training in the use of the system.*	5. Mapping software package or GIS, linked to ECAT. AND / OR:	MOW engineer or computer expert trained in use of applications programs.	11. Quality site maps on demand, at any scale, for spatial analysis of problems and planning of remedial programme.
7. Capability to use ECAT in conjunction with a maintenance management system.	*Integration of ECAT with program.* *Training in the use of the system.*	6. Maintenance management system linked to ECAT.		12. Use of ECAT in combination with MMS, for integrated pavement and earthworks maintenance strategy.

NOTE 1. Entries in italics indicate services provided by an outside agency such as a local consultant or TRL.

4.3 Countries in which ECAT has been used

Commissions to at least Level 2 analysis have been carried out on roads in the following countries:

Colombia
- Bogota - Villavicencio road

Jordan
- Amman - Adassiah road
- Amman - Jerash road
- Shuna - Salt road

Malaysia
- Kuala Lumpur - Bentong road
- North - South Expressway
- Tamparuli - Ranau road (Sabah)

Nepal
- Butwal - Tansen road
- Naubise - Mugling road
- Thankot - Naubise road
- Tribhuvan Highway (Raj Path)

4.4 Applications outside the highway sector

As mentioned in Chapter 1, ECAT is designed for use on a linear facility, where there is little interest in features far from the alignment. Roads lend themselves perfectly to ECAT analysis and, to date, development of ECAT has proceeded almost wholly towards the benefit of the roads sector. However, there exist other types of linear facility, of concern to DFID, that may lend themselves to monitoring by the same means. Examples are:

a. Railways

   Railways are very close to roads in their requirement for maintenance of cuttings and embankments. Some work has already been done on the application of ECAT to slope problems along railway alignments. The view of the slopes is sometimes obscured by trees or when slopes lie opposite each other in a deep cutting, but otherwise ECAT appears suitable for this application.

b. Pipelines

   Pipelines carrying liquids, sometimes for hundreds of kilometres, can spring leaks which go undetected for long periods by the pipeline operators. This can lead to localised pollution and occasionally other hazards such as toxicity or fire.

c. Electric power lines

   Electric power lines themselves give little trouble. They are maintained on a routine basis and faults quickly make themselves known. However, in hilly areas the ground upon which pylons stand is subject to erosion and mass movement.

ECAT ought to be suitable for monitoring the occurrence of ground degradation around these sites.

d. Irrigation canals

Embankments carrying irrigation canals can be subject to erosion, and may thus be suitable for monitoring by ECAT.

e. Slopes above reservoirs and of the associated catchment basins

Reservoirs are often built in mountainous areas and the slopes immediately surrounding them are subject to continual rise and fall in the water level, which alters the hydrology of the slope. Further away, within the catchments of rivers flowing into the reservoir, instability may take place that is hard to detect from vantage points within the valley. These slopes could be treated as a linear feature because interest is limited to slopes within the catchment of the reservoir, and the slope is continuous around the valley.

f. Coastlines

Coastlines present a range of problems to engineers as well as to ecologists. Cliffs can fall; coastal erosion alters the balance of longshore drift; lagoons, estuaries and coastal swamps become damaged by pollution or siltation. Coastlines, by virtue of their great length and difficulty of access, as well as an uninterrupted view of the subject, lend themselves to monitoring with ECAT.

g. River courses

River courses present similar problems to coastlines. ECAT should be suitable for monitoring bank erosion, localised changes of river course and flooding.

h. Urbanisation

Ribbon development of towns and villages along road alignments may be appropriately monitored by ECAT.

5 STRATEGY FOR IMPLEMENTATION

5.1 Introduction

A strategy for implementation of ECAT has two main aspects: a strategy for achieving a wider utilisation of the system among developing countries, and a strategy for enhancing the system itself. The main aim of the next development phase should be to put the system and its capabilities on a more established footing by a) implementing basic versions in more than one developing country and b) putting together a well-defined product with a recognisable customer image and publicising its existence. Achieving the latter aim, which is within TRL's control, should help greatly to achieve the former. Eventually, headway ought to be made in all the following areas:

1. Improvement and consolidation of the ECAT system into a standardised ECAT package.
2. Implementation of a basic version of ECAT in a number of countries.
3. Exploration of possibilities to use ECAT for monitoring facilities other than roads.
4. Extension of ECAT capabilities:
   - refining and broadening its current capabilities;
   - linking ECAT to other maintenance management tools and GIS.

Items 1 and 2 are closely linked; as noted above, achievement of the second should aid achievement of the first. Items 3 and 4 are covered in Chapter 4.

5.2 Producing a standardised ECAT package

ECAT has undergone development on a number of fronts and now needs to be regulated into a marketable package. Apart from the obvious dissemination advantage, TRL will be expected to support the product by answering queries from users. This service will be made much easier to manage by issuing a consistent product that is robust, with integrated components and clear procedures for operation.

5.3 Implementation of ECAT in countries abroad

This activity should be planned to run concurrently with the consolidation of ECAT at home, taking advantage of contacts already made with countries abroad. ECAT has been used on a trial basis in several countries but is implemented as an operational system only in West Malaysia. With a standard package available it should be easier to interest potential clients in taking up the system. Refer to Table 4.1 for an explanation of the implementations described below. Refer to Figures 2.1. and 2.2 for a view of the inter-relations between all components discussed.

It is probably not realistic to expect that Middle and Top level systems could be implemented without considerable further developmental effort, especially the tasks noted in Section 5.1. However, the basic requirements are suggested here for completeness. The two major inputs involved in operating ECAT are the collection of the aerial photographs (and the video-log) and carrying out the interpretations. Strategically, the main decision for an organisation to take when implementing ECAT is whether to buy in these inputs as services or to invest in the equipment and staff expertise to enable the host organisation to operate ECAT fully for itself.

5.3.1 Strategy for implementation of a Basic ECAT system

For a Basic level implementation the organisation would 'buy in' the collection and the interpretation of the earthworks data as services. Input from the host organisation would be concerned only with deciding upon actions to be taken in respect of earthworks found to be in need of repair.

Staffing requirements for the basic level of operation are given in Table 5.1. The engineer would be required to plan and organise the helicopter flight, arrange for the photography to be taken, travel on the flight and direct both the pilot and the photographer, manage the data acquisition process and carry out a Level 1 earthworks assessment. The actual time taken to complete these procedures would of course depend very much upon the number of earthworks to be assessed. This estimate is based on a single road containing perhaps two hundred earthworks. In addition to these duties, the engineer would need initially to allocate reference numbers to the earthworks ('sector' numbers) and may wish to create an earthworks inventory (Level 2 assessment) as a starting point for the monitoring programme.

Table 5.1 Staffing requirements for the Basic level of ECAT operation

Post	Expertise	Role	Training required	Time
Maintenance manager	Engineer	General management and commissioning of ECAT. Technical evaluation of earthworks and deciding upon remedial works required.	ECAT photo-interpretation. Basic engineering geology. Use of ECAT for queries. Familiarity with whole ECAT system.	2 man months p.a. (depending upon demand).

5.3.2 Strategy for implementation of Middle and Top level ECAT systems

The Middle and Top implementations denote a high degree of responsibility demanded for earthwork maintenance, such as would be found in organisations whose road networks contain many large earthworks, with severe problems. The need to carry out surveys periodically may make it worthwhile investing in the equipment and the staff training programme. The implementation of such a system would require a much greater degree of expertise, flexibility, organisation and finance within the host country. Table 5.2 gives an approximation of the staffing required, but this might appear very different in practice.

The running of an independent ECAT system would require almost as much expertise as exists in the UK. Until Basic systems are installed and running in several countries it would seem premature to encourage the installation of an independent system. However, there are many opportunities for research in this area. It would be extremely valuable for DFID, TRL and the host country if a research collaboration could be set up to develop ECAT in some of its more complex aspects.

Table 5.2 Approximate staffing requirements for the Middle and Top levels of ECAT operation

Post	Expertise	Role	Training required	Time
ECAT manager	Design engineer; highway engineer; maintenance engineer	General management and running of ECAT. Accompany air photo and video-log surveys. Assist ECAT interpreter with interpretation of air photos and video-log. Technical evaluation of earthworks; decide upon remedial works required. *Ad hoc* queries to database.	ECAT photo-interpretation. ECAT data processing, input and output. Use of ECAT for queries. Familiarity with whole ECAT system. Basic engineering geology.	4 m m p.a. [1] (depending upon demand).
ECAT interpreter	Geologist; engineering geologist	Accompany air photo and video-log surveys. Interpret ECAT air photos and video-log. Compile earthworks inventories and carry out Level 1, 2 and 3 earthworks assessments. Help engineer to recommend remedial treatments.	ECAT photo-interpretation. ECAT data processing, input and output. Familiarity with whole ECAT system. Basic highway and civil engineering.	2 m m p.a. [1] (depending upon demand).
Data manager	Engineer; computer specialist	Run and maintain ECAT database, software and peripherals. Maintain interface between ECAT and GIS[2] or MMS[3] software. Help users to pose *ad hoc* queries to GIS or MMS	ECAT data processing, input and output. Familiarity with whole ECAT system.	1 m m p.a. [1] (depending upon demand).
Photographer and ECAT equipment specialist	Technician; photographer	Arrange helicopter sorties and prepare video-log vehicle. Take air photos and video-log. Store and maintain air photos and ECAT files. Store and maintain equipment.	Use of equipment. Installation of equipment. Care and maintenance of equipment. Care of air photos and files. Familiarity with whole ECAT system.	1 m m p.a. [1] (depending upon demand).

NOTE
1. m m p.a. = man months per annum.
2. GIS = geographical information system.
3. MMS = maintenance management system.

6 CONCLUSIONS

The ECAT slope monitoring system represents a rapid and cost-effective method of evaluating the condition of earthworks and planning a programme of maintenance for a single road or a whole network. The chief use of ECAT is as an inventory of all earthworks on an alignment, with pictorial record. This can be used as a discussion tool when planning a maintenance programme, basically to identify earthworks that need urgent attention as opposed to those that can be left for one or more seasons, and the forms of remedial treatment that are appropriate in each case. If more than one epoch of aerial photography is available, the two sets can be compared to determine, for instance, the rate of degradation of a slope or the success of a remedial treatment.

A high technology approach to the problem of earthworks maintenance may seem inappropriate in a developing country setting, but in this case it makes sense. The investigation of earthworks problems is exceptionally difficult and slow work, and can be dangerous. As a result, it is impossible by normal methods to keep a watching brief on the deterioration of roadside slopes. Low-altitude oblique aerial photography is technically an ideal solution to provide an overall appraisal. The arguments against high technology solutions to problems are usually that complex equipment is expensive to buy and difficult to maintain, and that special skills and training are required in order to operate it and these are not found in developing countries. The equipment utilised by ECAT is certainly high technology, but PCs, databases, GPS, aerial photographs and video cameras are all items that are in common use in the engineering profession in developing countries, and none on its own costs as much as, say, a total station theodolite. The equipment, all standard, is no more difficult to obtain than other technical and electronic equipment. Helicopters are usually available for hire; in this sense, ECAT is easier to operate in a developing country than in Europe, where physical restrictions to flying are many. Helicopters are relatively expensive to hire, but sorties last only a few hours at most, and responsibility for the running and maintenance of the helicopter does not rest with the roads department.

ECAT has evolved over the period of a decade, and now comprises many components both hardware and software. Because ECAT evolution has taken advantage of advances in electronics as they have become available, developments have to some extent followed the pace and direction of improvements in the equipment. This has led to an uneven state of development for the modules. Another factor that has led to a certain piecemeal state of development is that trials have taken place in several countries as opportunity arose. The system current at the time has necessarily been tailored to meet the criteria of the organisation that commissioned the survey. Demand for a 'working version' to be available at these times has made it necessary to complete some modules while others have remained only partially implemented. The main components are all operational.

Some revision of terminology used within the system is required. Geotechnical terms have not been applied wholly consistently and are not always compatible with accepted usage. Terminology in hazard and risk assessment has also evolved and the use of these terms in ECAT needs to be brought into line with current usage. TRL will need to rectify this situation. However, the fundamental operation of the system will not be affected by any changes made under such a review. A technical aspect that requires more careful consideration is the use of single aerial photographs rather than stereoscopic pairs. Stereoscopic pairs undoubtedly provide more information but are very difficult to obtain satisfactorily with a hand-held camera at close quarters from a moving platform. A methodology to achieve this should be investigated.

Most of the ECAT components are in place and ready for service. However, for effective dissemination there are some immediate tasks, as follows. First, the terminology should be normalised, as noted above. Second, the system should be consolidated into a standardised package that has clear identity and function, with which a group of users can become familiar. Third, a dissemination programme, to get the system into active use in a number of countries, needs to be formulated and pursued. An important technical advance would be to improve its capability for assessing instability hazard and risk in a more quantifiable way. It would be useful to be able to link ECAT to a GIS, and as a longer term objective to incorporate ECAT as part of a maintenance management system. Further development would enable available ECAT data to be used to develop a comprehensive and widely applicable cost benefit model for earthworks. Finally, it will be valuable to explore the possibilities for using ECAT outside the roads sector for various forms of environmental monitoring.

The future success of ECAT lies with TRL. It seems certain that very considerable savings in maintenance expenditure can be made world-wide by employing ECAT as a planning tool, though these are still not adequately quantified. However, ECAT will not sell itself; outwardly it is too sophisticated and complex. TRL will need to undertake a marketing strategy that demonstrates to engineers and budget controllers how it will improve the condition of earthworks whilst reducing maintenance costs. The information obtained from aerial photographs is very revealing, and engineers readily appreciate the nature and scale of the maintenance task once they have seen the evidence. Planning a programme of remedial works becomes far less daunting when the problems are laid out upon a desk, presented for discussion and resolution among a peer group.

7 REFERENCES

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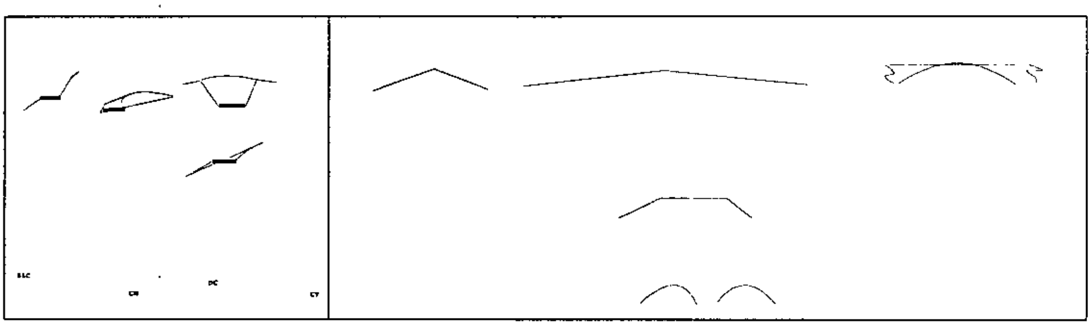
8 APPENDIX 1. EARTHWORKS ATTRIBUTES FORM

ROAD NAME:

FIELD NAME	PARAMETER
Sector No	
Location (Km)	
Grid Northings	
Grid Eastings	
Elevation	m
Photo No	
Reference Photo	
Approx Photo Scale	1:500 1:1,000 1:2,500
Cut-slope height above road	V-Low Low(10m) Medium(20m) High(50m) V-High
Main slope height	V-Low Low Medium High V-High
Approx sector length (m)	50 100 200 300 400 500
Approx slope gradient	(20°) (35°) (45°) (60°) (75°) (90°)



(contd)

UPPER-SLOPE	
Cut slope Type	Side slope cutting / Cut-Back / Double cutting / Cut-fill / Natural / Gully / Hairpin
Main slope Shape	Vee / Wide-Vee / Dome / Flat-Top / Long / Double / Triple / Multiple
Slope on Bend	Concave / Convex / Straight / Twisty / Hairpin / Gully
Type of Slope failure	Erosion / Slump / Slide / Scour / Rockfall / None
Slope Cover	Mesh / Gunite / Grass / Terrace / Natural shrub / Trees / Mixed / Sparse / Bare
Above cut slope	Agricultural / Paddy / Natural / Forest / Hummocky / Road / Houses/ Bare
Geology	Igneous / Sedimentary / Metamorphic / Soil
Rock Structure	Adverse to slope / Not Adverse / None / Not Visible
Catchment Value	(low) 1 2 3 4 5 (high)
Catchment Inflow to slope	(low) 1 2 3 4 5 (high)
Rockfall risk	(low) 1 2 3 4 5 (high)
Visual risk	(low) 1 2 3 4 5 (high)
No of visible slides	1 2 3 4 5
General Condition	Good / Average / Poor / V-Poor
Main cause of failure	Top water / oversteep / poor material / Agriculture / Poor toe support
Repairs	Needs Repair / Just Repaired / Let Degrade / No Work Needed / Monitor
Potential slides	Yes/ No/ Serious
EMBANKMENT	
Embankment Type	Side slope / Saddle /River slope / Flat
Visual risk	(low) 1 2 3 4 5 (high)
Emnbankment Steepness	(Shallow) 1 2 3 4 5 (steep)
Embankment height	Low / Moderate / High / V-High
Embankment cover	Mesh / Gunite / Grass / Terrace / Natural shrub / Trees / Mixed / Sparse / Bare
River Position	Close / Marginal / Safe / Far
River Incutting	Yes No
Embankment Condition	Good / Average / Poor / Very Poor
Type of Failure	Collapsed / Slumped / Scoured / Lost / None
Cause of Failure	Culvert flow / Toe scour / Water from road / Weak material / Poor compaction
Repairs	Needs Repair / Just Repaired / Let Degrade / No Work Needed / Monitor

(contd)

	EXISTING ENGINEERING WORK
DRAIN;Natural Channels	Yes No
Side Chutes	Yes No
Top Cut-Off Drain/Bund	Yes No
Central Chute	Yes No
Culvert	Pipe / Box / Both / Slab / None seen / Not identified
Other	
For	Slope/ Embankment / Both
WALLS; Protection	Slope Embankment Both None
Support	Slope Embankment Both None
Catch-wall	Slope Embankment Both None
Concrete	1 2 3 4 5 6
Masonry	1 2 3 4 5 6
Gabion	1 2 3 4 5 6
Anchor	1 2 3 4 5 6
ROAD; Visibility Factor	(Good) 1 2 3 4 5 (Poor)
ROAD; State of Road	Good / Average / Poor / V-poor

	OTHER FEATURES
Rural Development	One House / Group Houses / Scattered Houses
Where	Above Road / Below Road / Both
Bridge	Good / Damaged/ Check
Subjective Priority	A B C

9 APPENDIX 2. HELICOPTER SURVEYS

A helicopter is able to fly slowly, at low altitude, in steep and tortuous terrain where necessary. Thus, it can follow winding routes and bring the camera into position to take large scale photographs from a variety of angles as necessary. Its flight is very flexible and can be kept under the command of the camera operator. Helicopters are relatively expensive to operate but are very efficient because a lot of ground can be covered in a short time.

Desirable helicopter characteristics for the purpose of ECAT survey are as follows:

- A removable door or large port that can be opened for camera operation. Photographs cannot be taken through a closed window;
- An aircraft that affords a good general view for the navigator;
- A small (manoeuvrable) machine;
- Preferably, a quiet machine.

Certain technical skills are desirable for those undertaking helicopter surveys:

1. A knowledge of photography and experience of taking photographs with a manual camera or under varying lighting conditions.
2. Familiarity with and care of photographic equipment, to make sure that it is working properly at all times (e.g., to check periodically that the film is winding on correctly).
3. Capability to brief the pilot in a way that will place the photographer in the best position to take good photographs and minimise wastage of time - by having to circle for repeat shots, for example. This comes with experience. Show the pilot some photographs taken on previous expeditions to demonstrate what is to be achieved.
4. Some knowledge of the constraints under which helicopters have to operate, e.g., awareness of hazards, maximum flying time, nearest distance allowable to approach the ground. Also, basic safety procedures and general protocol and etiquette when flying as a passenger in a helicopter. The helicopter operator can give advice on these points.
5. Some knowledge of security clearance procedures, usually required before permission is given to fly. The helicopter operator can give advice on flight clearance, and perhaps can arrange it.

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