TRANSPORT RESEARCH LABORATORY

TITLE The analysis of earthwork and slope deterioration from aerial photographs

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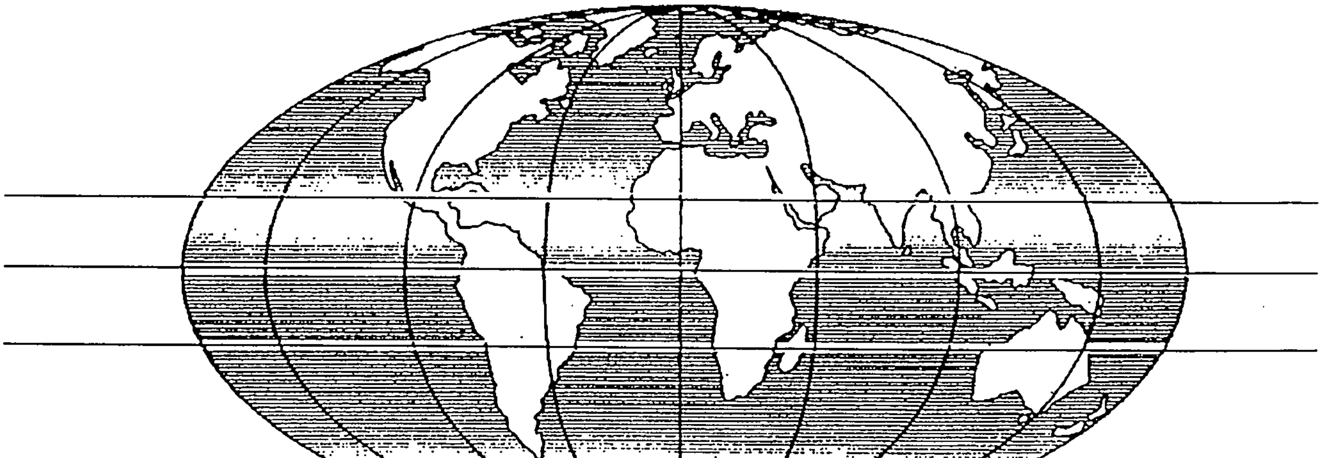

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SUMMARY

Roads, railways and coastlines are all large scale linear features usually incorporating many earthworks. These earthworks are subject to deterioration and may fail causing serious problems. A significant number of these failures could be prevented if all earthworks were monitored frequently and early signs of deterioration noted so that improvements could be made. Inspections on foot, however, are very costly and time consuming and therefore are rarely undertaken. A technique to monitor earthworks and provide information for their repair has been developed at the Transport Research Laboratory (TRL). The analysis procedure employed is designed to be used on linear features, when many earthworks have to be evaluated quickly and inexpensively, and concise information about their location and cause of deterioration is required. The technique used to record earthworks and a description of the analysis procedure is provided, with an example showing the results of the analysis.

1.0 INTRODUCTION

Earthwork operations include the modification to natural slopes for the construction of transport systems, building projects, and other civil engineered structures. In recent years the scale of earthwork construction has increased considerably, particularly in the more mountainous regions of the world although coastal situations have also become significant. This increase has led to a greater number of earthwork failures that in some cases have resulted in large scale catastrophes, including train derailments, fatal road incidents and the collapse of buildings. Less serious but also showing a significant increase has been the deterioration of many natural slopes as a consequence of earthwork modification, which is disfiguring to the landscape and effects the environment in terms of soil loss and sedimentation.

Most of the earthworks problems stem from the deterioration of slopes caused by erosion and weathering, which has been allowed to progress unchecked. As these processes are gradual there is time to correct many problems before failure occurs and this is why the inspection of all earthworks at frequent intervals is essential. However such is the increase in earthwork construction worldwide that checking all slopes frequently, using traditional site inspection methods, which are slow and demanding, is beyond the means of most authorities.

This difficulty in keeping up with inspection routines has occurred to a large degree throughout the engineering industry but is generally solved by developments in semi-automated recording, analysis and data handling techniques. However, applying the same processes to earthworks has been slow because of their large scale and complexity. Now however a suitable procedure, based on the use of a helicopter to obtain very large scale aerial photo-records, has been developed and extensively tested at TRL, [1] Heath W.et.al.(1996). Although intended for highways, the procedure, particularly the recording and analysis stages, has applications in all situations where there are many earthworks or slopes that may fail. Trials carried out on highways in a number of countries have demonstrated convincingly that the results obtained are very compatible with those being achieved by engineers working on site, while often being quicker and cheaper to obtain [2] Heath W. et al. (1995).

The paper describes just one aspect of the technique, the analysis of the aerial photographs. It is an analysis procedure designed to be used on any linear feature such as roads, railtrack or coastlines, where the continuous recording of earthworks, over distances of twenty-five kilometres or more can be applied. The analysis procedure is structured to deal with hundreds of earthworks rapidly and is therefore a well organised and systematic strategy, using a computer database to control the procedure and store information.

ASSESSING EARTHWORK CONDITION

2.1 Background.

There are many references siting examples of the use of aerial photographs for the hazard mapping of landslides, see [3] O'Connor E and Northmore K. (1994), some of which have been more successful than others. Those results that have not been encouraging have relied on the analysis of aerial photographs that are inappropriate, ie medium to small scale black and white images, intended for medium-scale topographic mapping. Usually they do not have sufficient detail for landslide studies.

The procedure being described is based on earthwork records consisting of very large scale colour images intended solely for this task. With the correct techniques, obtaining the aerial photographs is quick and inexpensive, see [4] Heath and McKinnon (1994), and savings in the time needed to analyse more than compensates for the trouble of obtaining these special images.

One question that often results in some controversy concerns the advantages to be found in visiting earthwork sites as opposed to examining aerial photographs in terms of locating problems, when doing both is not practical. While there is no doubt that the best way of solving a complex geotechnical problem is in the field, where tests can be carried out, the reverse is often true when there are many earthworks to examine, the problems are far ranging, and access is difficult because the slopes are steep and dangerous. Then a systematic approach invariably proves beneficial in that the analysis can be carried out under controlled conditions and a very wide range of information can be obtained and sorted in a computer database.

Furthermore such is the disparity in the range of useful information being obtained from present on-site investigation methods that a defined procedure that provides a consistent standard of information wherever it is used is long overdue.

2.2 Suitable Records.

A study has been made at TRL to determine the best method of recording earthworks on highways and the most efficient means of analysing and interpreting the information for engineering purposes. This study has consisted of obtaining and analysing more than 5,000 aerial photographs of earthworks on roads in three countries. Altogether problems affecting approximately 10,000 earthworks on 600Km of road have been studied. In defining the ideal recording medium for earthworks the following factors have been considered: i) The records of earthworks must be quick and cheap to obtain; ii) The record must enable the analysis process to be completed quickly; iii) There should be other uses for the records such as assisting with the planning of repair work.

Based on these factors the results of trials indicate that the ideal earthwork records consist of colour aerial photographs at an image scale of approximately 1:1,500, which in survey terms is very large indeed. Two photographs are needed for each site, one at an oblique angle to the ground and the other vertical. The former is best for locating problems while the latter provides a wider view of the catchment area and is also useful as a basis for making simple measurements and planning any repairs. The photographs are obtained using a helicopter that is economical providing there are a reasonable number of slopes to look at and that correct helicopter operating logistics are adhered too.

The photographs need to be produced on a medium format, (70mm) film, as smaller formats lack sufficient detail. In addition to the records of earthworks some means has to be found of labelling each record with location information. For highway earthworks this consists of a videolog, recorded from a vehicle, containing a continuous record of the road with chainage details and grid coordinates from a GPS system.

The aerial photographs provide a continuous record along a road, railtrack or coast line, with each image recording a 250m long section. This is termed a *'sector'* and has, within the data system, a unique reference with its location and grid coordinates. The first task prior to analysing the earthworks is to fix the ground location of all aerial photographs by comparing each image with the videolog record.

3.0 THE ANALYSIS PROCEDURE

3.1 Three stages

There are three aspects of the earthwork condition analysis: i) finding any signs of deterioration; ii) the likely cause and likely consequences of the deterioration; iii) what the deterioration and any potential failure implies in terms of the engineering aspect of the earthwork, see Figure 1.

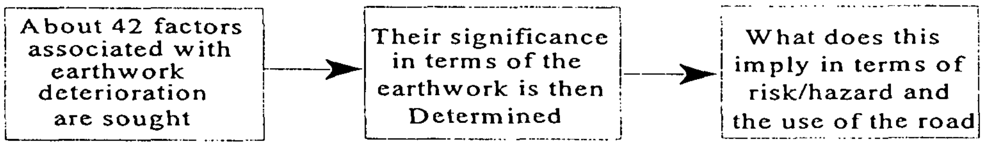

Figure 1. The three main factors connected with the analysis of earthworks

The range of factors associated with any earthwork deterioration is quite extensive, as shown in Table 1. Normally, however, the terrain conditions, catchment size, type of geology, etc. all give the experienced engineer clues to what forms of deterioration are likely to be found, and therefore the process of analysis is quite rapid.

The next task is to estimate both the short and long term consequences of the deterioration in terms of potential failure. This is quite a complex task as not only the scale of the problem is significant but its position in relation to the road and the suddenness of failure. For example a single boulder falling onto a vehicle can kill its occupants as surely as a landslide. Another factor that needs to be taken into account is the rate of further deterioration and how this might increase the risk of failure. The main difficulties are in allowing for exceptional events that accelerate deterioration such as flooding.

Finally there are the consequences of any problems to road users and traffic. Limiting any hazard risk is normally an important priority, and this extends beyond preventing the failure of earthworks. For example there may be situations where excess water from slopes makes the road slippery, or there are steep unprotected embankments. The earthwork failure risk is the next consideration but is related to both the cost of making repairs and the possible disruptions to traffic. Some earthwork or slope failures are simple to deal with while others may take weeks to clear. Equally certain sections of road are without detour routes so that failures within these zones are particularly critical. The determination of repair priority needs to be based on such factors.

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. 5) River scour. 6) River turbulence or other flow characteristic causing erosion.

Table 1. A list of earthwork deterioration features that can be identified on the images.

3.2 Determining repair priorities to produce risk maps

For the analysis five criteria covering the conditions mentioned are used: i) the hazard risk to road users; ii) the earthwork failure risk; iii) the difficulties of repair; iv) the likely effects on traffic if failure occurs; v) likely long term earthwork problems. Each criterion is given a rating from 1, low risk, to 5 high risk and the results entered into a database. The database uses a look-up table to allocate a repair category and hence a priority based on the rating given to the criteria. For example Figure 2 shows the number of sectors in each group of the five categories and the overall categories for 'A' high priority repair, 'B' lower priority and 'C' no attention required.

The chart shows that almost 40% of sectors are graded 4 and 5 in the criteria, with the exception of 'repair cost'. For hazard risks to road users and failure risk there is a significantly high number of sectors, 12% and 20% graded as 5. This is reflected in the overall state of the road with 40% of earthwork sectors requiring immediate attention, repair priority 'A'. From this the road can be assumed to be in a very poor condition.

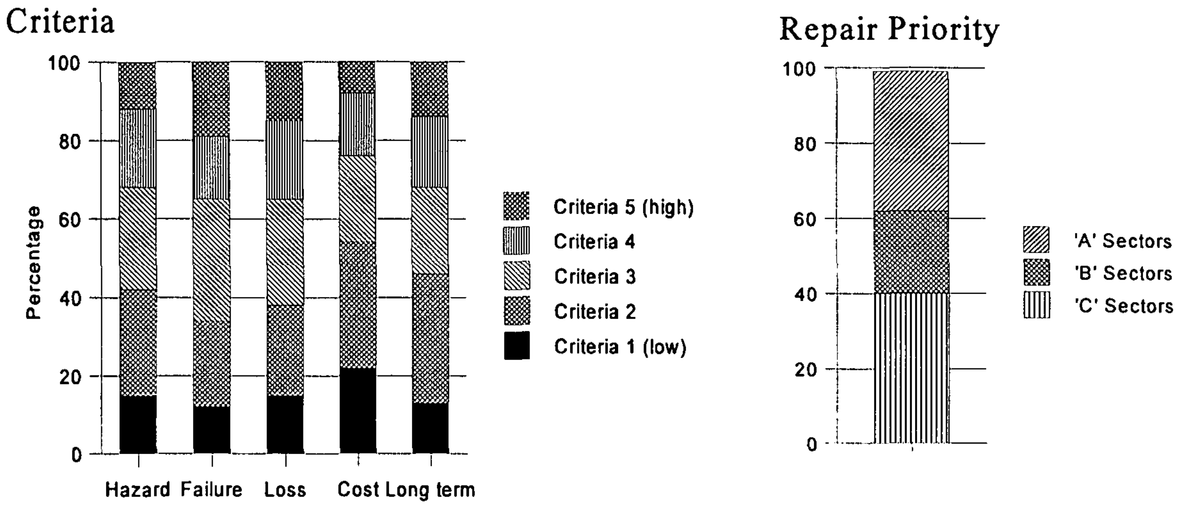

Figure 2. Chart showing the five risk criteria and repair priority.

The results obtained from the assessment of the five risk and hazard criteria, described for the first stage of the analysis, are entered into the database and computer hazard and risk maps are produced. The range of maps that can be specified includes 15 categories of slope problems and 12 categories of embankment problems, see Table 2.

SLOPES			
High risk rock-fall	Poor bedding structure	Slides & slumps	Excessive erosion
Gradient > 1.25:1	Larger catchment area	Building development	Agricultural activity
Little vegetation	Great height	Potential failures	Severe failure risk
Need repairs	Need monitoring	Water running onto road	
EMBANKMENTS			
river/slope type	Saddle types	Side-slope type	Very steep/dangerous
Very high	River is very close	River in-cuts on toe	Poor condition
High failure risk	Culvert erosion	Need repairs	Need to be monitored

Table 2. Some of the risk maps that can be produced by the database.

3.3 The Inventory.

In some instances risk maps may be all that is required. However a computer database provides the means of collecting a range of data from the earthwork records that can help in analysing problems, implementing repairs and making improvements to future earthwork design and construction methods. For the highway earthwork inventory a list with up to sixty questions is used on each road sector aerial photograph, see Table 3.

Two important functions of the earthwork inventory are: i) As a long term storage system for earthwork data that can be used for developing empirical design methods based on the experience of how certain earthwork features have functioned in the past; ii) Using statistical analysis procedures, to compare the quality and functioning of earthworks within a linear system or different linear systems within a network.

LOCATION					
Sector No	Location	Grid Northings	Grid Eastings	Elevation	Photo No
Photo scale	Ref. Photo	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
GENERAL					
State of Road	Road Visibility	Rural Develop	Bridges	Traffic/Heavy	Traffic/Light

Table 3. Some of the items used in the earthwork inventory.

3.4 The detailed evaluation of a problem.

On all sectors of a road where there are serious earthwork problems, classified as 'A' category priority, an extra stage of analysis can be carried out so that the cause of the problem and the options for repairs can be determined. This is based upon drawing details of the failure found in the oblique aerial photograph on an overlay. For this purpose earthwork failure types are divided into eighteen categories, see Table 4. The database has a diagram for each type of failure that helps the engineer carrying out the analysis to identify relevant features.

CUT-SLOPES					
Deep circular slides	DCS	Shallow circular slides	SCS	Lack of Toe Support	LTS
Avalanche-type slide	ATS	Surface erosion failure	SEF	Gully flow failure	GFF
EMBANKMENT					
Embankment Toe loss	ETL	Emb. culvert erosion	ECE	Embankment collapse	ECF
Emb. edge failure	EEF	Pavement cracking	PEC	Pavement seepage	PFS
SLIDES					
Slip landslide failure	SLF	Creep landslide failure	CLF	Failure through both	FTB
Ancient slide failure	ASF	Rock-fall failure	RFF	Boulder fall failure	BFF

Table 4. A list of earthwork failure types with abbreviations as used in the ECAT analysis.

4.0 AN EXAMPLE

In this example of the analysis procedure the three stages are used, as for important highways all of the information that the three stages of analysis provide is considered essential. However, for a less important secondary road or other linear feature one stage of analysis might be sufficient. This may be to produce risk maps and repair priorities, (stage 1) an inventory of earthworks, (stage 2) or to identify serious earthwork problems and determine the best action to take, (stage 3).

4.1 The Procedure

The aerial photograph of a road sector shown in Figure 3 is reproduced to one third true size in black and white. It is a section of the Kennon highway in the Philippines at kilometre 238.2 from Manila and referenced as Sector 5.

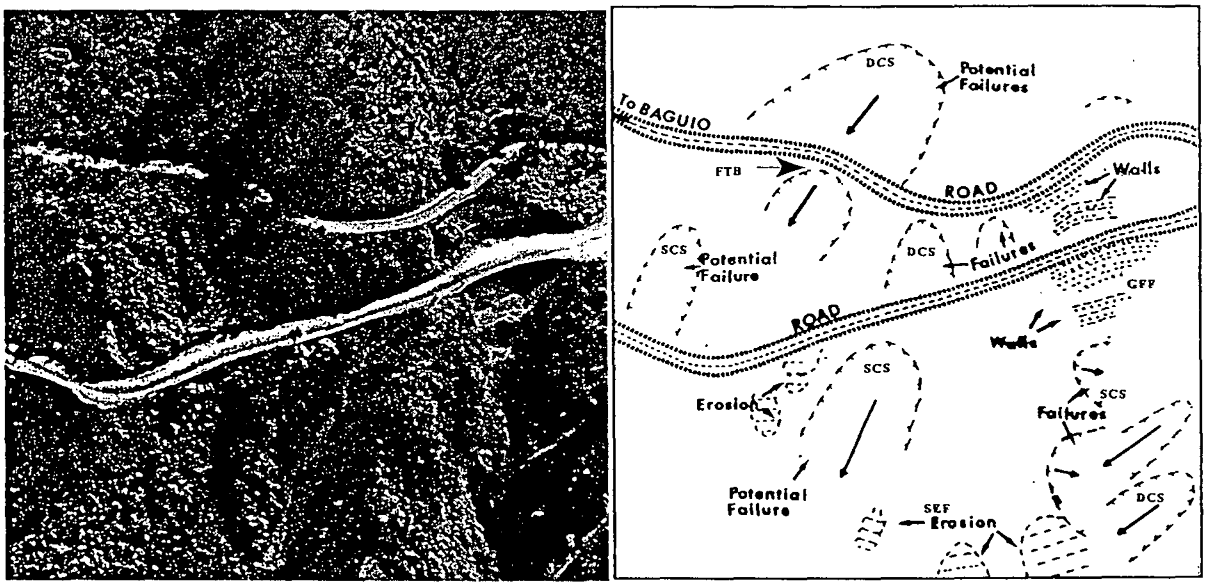

Figure 3. An aerial record of hairpin section with overlay showing details of problems.

Stage 1. i) The location of all earthworks is determined from the videolog and recorded on all earthwork records. Aerial photograph numbers, location information and other references are entered into a database.

ii) Values for the five criteria are determined and entered into the database where repair priorities are calculated for each road sector. Risk maps are produced from the database information. Table 5 lists the criteria and repair priority for this one sector.

Hazard	Failure	Loss	Cost	Long term	Repair Priority
4	5	5	5	4	A

Table 5. Risk criteria and repair priority for sector 5

A section of a risk-map showing places where the river cuts-in and is eroding the embankment between kilometres 218 and 223 is shown in Figure 4. These maps as produced from the computer are relatively simple but can be upgraded with information from the earthwork inventory.

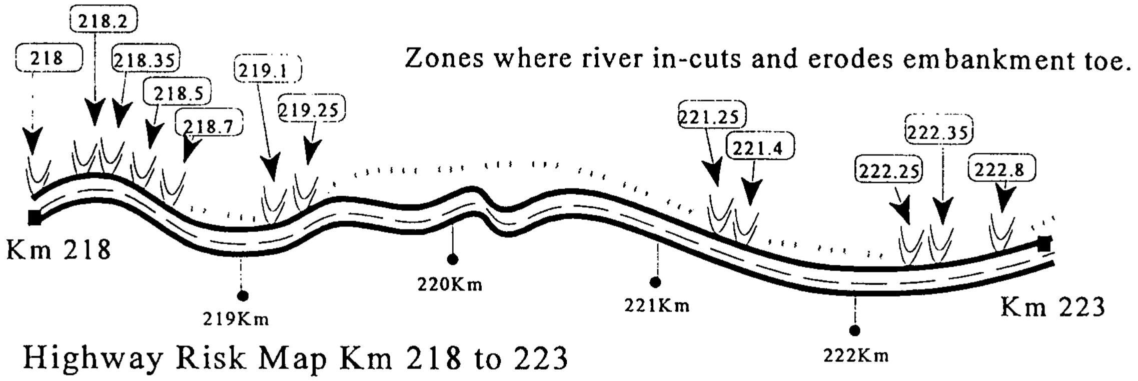

Figure 4. A risk map showing where the embankment is at risk.

Stage 2. A questionnaire containing approximately 60 statements relating to earthworks is used with each aerial photograph. About twenty sectors of road can be completed per hour, ie 5 kilometres. The information is entered into the database where it is used to produce graphs and tables about earthwork features.

As an example of the type of information the inventory can provide Figure 5 is a graph showing the number of earthwork sectors in each priority repair category, for each five kilometres of the road. Therefore not only the number of serious problems but their distribution on the road can be seen. In this instance it shows that serious earthwork problems show a definite increase towards kilometres 20 to 25. More than 100 similar graphs or tables containing information about a wide range of earthwork features are ready to use in the database.

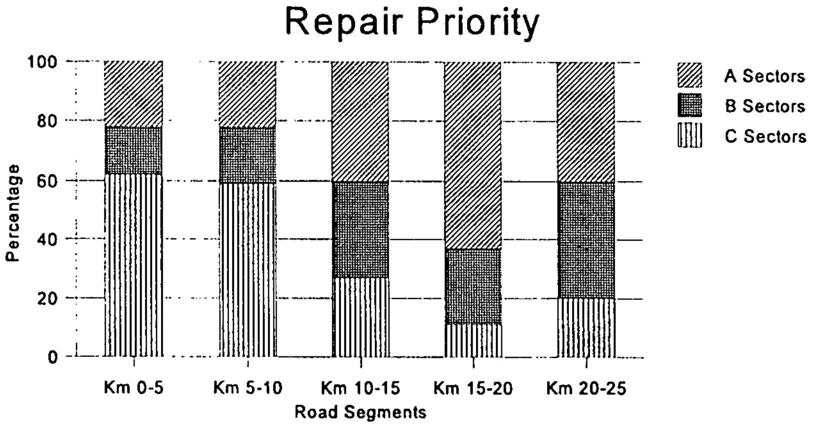

Figure 5. The distribution of serious earthwork problems over twenty-five Km of road.

Stage 3. The type of failure is recorded on the overlay for each earthwork problem as shown in Figure 3. The earthwork failures shown in Figure 3 include i) deep circular slides, ii) a failure through both slope and embankment, iii) shallow circular slides, iv) surface erosion failures, v) gully flow failure. The database diagrams, see section 3, Table 4 for a list of these, are shown in Figure 6. The next stage of analysis is to determine the cause of each type of failure and consider the options that can be used to make repairs.

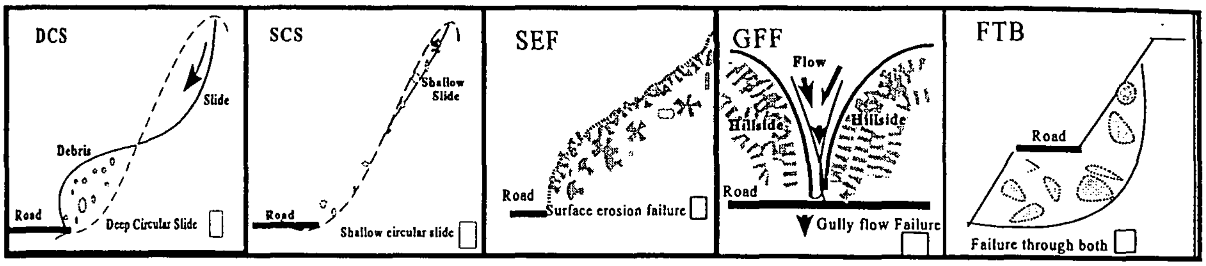

Figure 6. The five earthwork failure types shown in Figure 3.

Notes are also made about the problems to the slope and embankment with details about what action is recommended, the size of the task and an estimate of the long term stability in the area. These details, see Table 6, also go into the database. Finally the colour image and overlay are scanned to produce digital images that are held in the computer database.

ENGINEERING NOTES:-

Sector Number :-	5
Earthwork Type:-	Hairpin Section.
Condition of Slope's :-	There are three zones where slides have moved through the two road levels. In two of the zones the road section has been re-aligned at some stage. In of the locations there are signs of further deterioration which must be arrested. The other notable aspect are the areas of erosion, which need to be controlled.
Condition of Embankment:-	Hairpin section, notes as those for slopes.
Action Suggested:-	The existing slope drainage system appears to be inadequate on the complex section. As a result the slopes are eroding and also becoming excessively saturated. Improved drainage is required to arrest the deterioration.
Size of Engineering Task :-	Large.
Long-term Stability :-	Generally poor, slope and embankment failures are likely unless extensive work is undertaken.

Table 6. Details of earthwork problems for one sector of road.

At this stage a visit is made to carry out site checks on the larger earthworks to confirm the recommendations for repairs.

CONCLUSION.

At present there are many instances where engineers are given unrealistic times to carry out earthwork assessments over hundreds of kilometres of terrain. As a result only the most serious failures are recognised. Many earthwork deterioration problems are left to continue and develop into further failures.

The techniques described in this report can be implemented in all countries where linear systems of earthworks exist and need to be checked frequently. The information about earthworks, involving up to three stages of analysis is very comprehensive and consistent for all linear systems. This means that information about earthworks is available for all stages of a project from the initial assessment through to implementing the repair work. It is a procedure that local engineers can adopt with very little training or experience.

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