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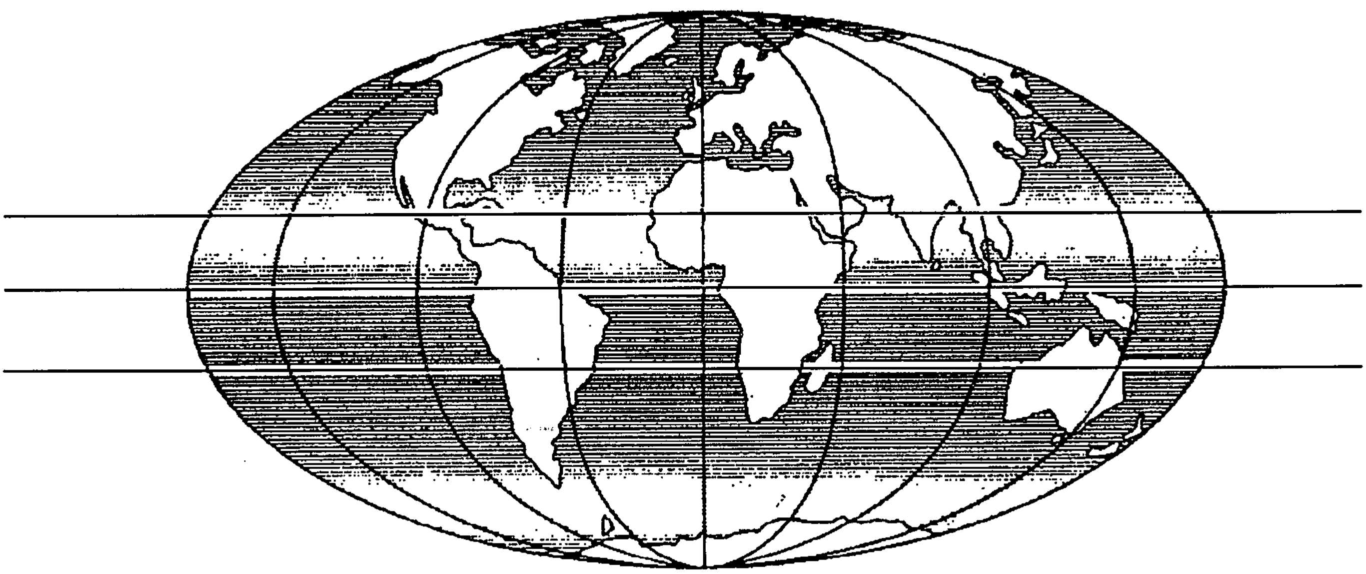
TITLE **Earthwork monitoring: a project management system**

by W G Heath and B McKinnon



Overseas Centre
Transport Research Laboratory
Crowthorne Berkshire United Kingdom

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EARTHWORK MONITORING: A PROJECT MANAGEMENT SYSTEM:

HEATH W & McKINNON B.
Transport Research Laboratory.

ABSTRACT:

The paper describes a highway earthwork project management system which has been developed at TRL (Overseas Centre). Using a technique involving very large scale aerial photographs for recording earthworks it enables a rapid assessment of their condition to be made. The information is organised in a computer database and used with project management software to provide answers to many of the problems highway authorities have to deal with. These include repair priorities, cost estimates, designs, specifications, risk criteria, remedial work recommendations and repair strategies, for which the use of vegetation for slope protection purposes is relevant. The technique has no major investment cost and is inexpensive to use.

INTRODUCTION:

The short service life and wide scale failure of earthworks on many roads in developing countries is a cause for concern. Such problems could be reduced significantly by using more appropriate earthwork design, protection and drainage as well as improving construction methods. However the relevant authorities usually do not have the appropriate technical resources to achieve this or the necessary funds to implement these better standards during road construction. An alternative strategy for prolonging the useful life of mountain road networks is to ensure that earthwork deterioration is arrested before it progresses to the stage of failure.

To achieve this there are two requirements. The first is a means of assessing the condition of earthworks quickly and at low cost. This must be followed by a method of evaluating the data and providing the authorities with sufficient information to carry out timely repairs. In effect an earthwork project management system.

Such a system has been developed at TRL (Overseas Centre) and tested on a number of roads in Asia with encouraging results. It is based on recording earthworks using a helicopter and subsequently analysing the results under controlled conditions. Information is then entered into a database which forms the basis of the earthwork project management system. All of this can be achieved very quickly and at low cost. It means that the highway authority has no need to invest in expensive equipment, is provided with a comprehensive review of all earthwork problems and is given easy access to information that is needed in making decisions and allocating budgets.

1. THE PROBLEM:

1.1 Earthwork construction difficulties:

The construction of earthworks on mountain roads may account for fifty percent or more of the total road cost and therefore building such roads is inevitably expensive. Having incurred such a high initial expense many highway authorities are surprised to find that high repair costs for earthwork failures are exceedingly common. Such problems are most widespread in tropical countries where high rainfall or weak slope materials contribute to earthwork failure. The term earthwork is here used to describe cut-slopes, embankments and natural slopes modified in some way for road construction purposes.

1.2 The problems highway authorities face: The fact that there is high rainfall and the materials utilised for earthwork construction are vulnerable to alteration from excess water indicates that adequate means of designing and protecting earthworks, including vegetation, should be employed. However at the earthwork construction stage it is not always clear how these design and protection measures need to be applied. Consequently there is the problem of applying protection in areas where it is unecessary, and this means high construction costs which many highway authorities can ill afford.

The alternative is to monitor the earthworks to identify the critical sections before deterioration becomes too advanced and then to modify the structures by such techniques as drainage and vegetation protection. Justification for this early action comes from the need to avoid the high cost of repairing earthworks once they have failed. Studies by Piteau (1978), suggests that the reinstatement work on failed earthworks can easily exceed the initial construction costs.

All too often however the earthwork deterioration is not recognised until wide scale earthwork failures have commenced to occur and by then the damage to other slopes cannot be arrested. Therefore earthworks are left to deteriorate because of the lack of an efficient condition-assessment technique. A typical mountain road may have more than 250 earthwork structures for each 100 km of highway. The problems of monitoring all of these are immense. Even when a condition assessment of earthworks is made it provides such a large amount of information that road authorities may have difficulty in dealing with it.

2. THE SOLUTION: A SYSTEM OF EARTHWORK MANAGEMENT:

The answer to these difficulties lies in the use of a computer earthwork management system. Such a system needs to be based on the following;

2.1 A rapid, and inexpensive means of collecting earthwork condition information: Ideally earthworks should be monitored regularly, with new monitoring repeated every one to two years depending upon the importance of the road and the likely problems. A typical length of highway network may be 500 km and it is likely to involve 2,500 earthworks or more. The task can be undertaken by engineers, examining the slopes on foot taking notes. But usually this method is avoided because it is very time consuming and therefore costly.

Engineering management systems, such as those for pavements, usually involve a method of recording the condition and then analysing the results under controlled conditions. Obviously this is a more difficult task in the case of earthworks because of the vast amount of terrain involved.

2.2 An analysis covering a very wide range of earthwork features:
The objectives of an earthwork assessment must be to identify areas where primary deterioration is occurring and rectify it. However this is not enough, the cause of the problem must be identified and steps taken to stop it re-occurring. This requires very detailed analyses of each situation. The analysis needs to be controlled by well defined procedures so that results are consistent.

The system described here goes beyond the study of immediate problems by putting them in context with the overall condition of the highway. This is achieved by making a general inventory of the highway. A long term objective of such an inventory is to evaluate design methods and introduce improved practice.

2.3 The storage of the information:
The storage medium should take information for any number of earthworks and allow additional information to be added to it easily. Computer database systems are ideal for this purpose but the type must be chosen carefully and meet a range of conditions. Ideally the information about earthworks should have a criterion that places each individual slope in a hierarchy depending upon its need for attention. Information should be stored in groupings which reflect such a need.

2.4 Providing easy access to information:
Highway authorities need to use the information about earthworks in a number of ways including the requirement to make decisions about the allocation of maintenance resources, to organise priority repairs and to compare the overall condition of a highway. The information should be presented in a manner which aids these objectives.

2.5 Methods of supporting the earthwork information:
As well as providing details about individual earthwork problems and the overall condition of highways the earthwork project management system can provide a range of management 'tools'. These may assist the road authority to carry out tasks and make decisions. For example it can give guidelines about how repair-work should be allocated; provide the means of carrying out a wide range of design tasks; list appropriate specifications for each task; cost the repair work for earthworks and provide a unique means of making risk assessments.

3. DESCRIBING AN EARTHWORK MANAGEMENT SYSTEM:

In areas of the world where slope instability problems have been brought under control, for example Hong Kong, Brand (1984), a rapid method of assessing earthwork condition has been found to be an important element in solving problems. Techniques to accomplish this earthwork condition assessment, including aerial photo-interpretation and photogrammetry, have been developed at TRL, Heath (1980). These techniques have been used on lengthy sections of highway on the Malaysian Peninsula, Heath et al. (1992), Sabah, and Nepal. They now form one element of the earthwork project management system being described. The components are as follows.

3.1 The aerial photographs:

Aerial photographs are used to record earthworks.The objectives are to record sufficient detail about earthworks for linear features only a few millimetres wide to be recognizable. This has meant testing various aerial photography techniques and finding the most effective method. It consists of using both oblique and vertical colour photographs at photo-scales ranging from 1:1,000 to 1:2,500. It has been found that oblique aerial photographs can be analysed quickly and inexpensively to identify the information needed for the inventory. Stereoscopic images are not required as they take much longer to analyse and any extra information that is obtained normally does not justify the extra effort involved. Figure 1 shows oblique and vertical photographs of a bridge, chosen to assist the reader in making comparisons between the two images. They are shown mounted on index cards, the function of which is described in a subsequent paragraph.

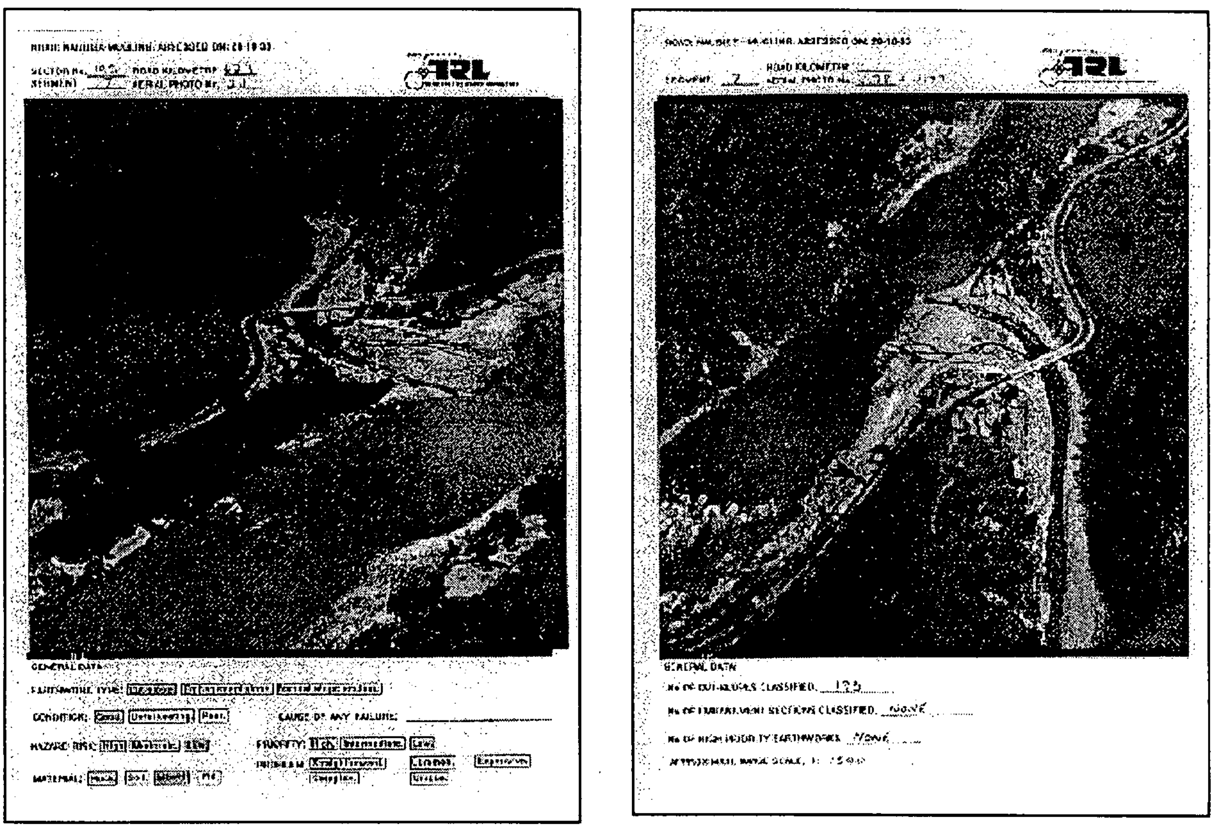

Figure 1. Large scale oblique and vertical aerial photographs.

Each oblique aerial photograph records approximately 250 m of the road. This is termed a 'sector' and there is generally one or more earthworks within each sector. For sections of road where there are no earthworks there are no oblique photographs. The vertical aerial image is at a slightly smaller scale and covers approximately 400 m of road. These provide a continuous record of a road. For a typical highway of about 100 km there are generally 250 oblique and 250 vertical 240 x 240mm images to be analysed.

Obtaining the aerial photographs requires the use of a helicopter. These can be expensive to hire and therefore the technique has been refined so that the minimum hire time is necessary. For example all earthworks on a 100 km length of highway take 1.5 hours of helicopter time to photograph. Such photographs can be taken in weather conditions that are not normally considered suitable for aerial photography because the operation takes place at very low altitude.

The aerial films are sent to a professional processing laboratory and one set of 240 x 240mm colour prints is produced. During this stage earthwork location information is collected from the road. This means that the kilometre position of every earthwork must be recorded and the appropriate aerial photograph labelled. Also the grid coordinates of each earthwork are recorded using GPS (Global Positioning Satellite). This allows road authorities to link the earthwork project management system to a GIS (Geographic Information System). The complete task of taking aerial photographs and recording earthwork location information is rapid, taking approximately four days for 100 km of highway.

3.2 The analysis:

In developing a suitable technique the objectives have been to minimise the time it takes to analyse images, so that the system remains competitive with existing earthwork condition assessment methods while ensuring that the analysis process is made as accurate as possible. This is achieved by carrying out the analysis in three phases. The first being the assembly of an earthwork inventory. A questionnaire containing 50 questions is used and information entered directly into a database. The task is carried out by an assistant who has computer on-screen guidance in the form of prompts and pictures to help make the correct decisions. This ensures that the information collected for all earthworks remains consistent.

Following this each of the aerial photographs is examined by an experienced earthwork engineer who is looking for any problems. If problems are found then the cause and possible remedial solution is also recorded. This is in free-hand note form in the database, similar to methods the engineer would use on site. However some structuring of the notes takes place to allow an interrogation of the information in the database.

A third stage of analysis takes place to examine causes of failure but only for earthworks which have been found to be in a poor condition. To date this has consisted of approximately one third of the earthworks on the roads which have been examined.

3.3 A criterion:

The method of earthwork grading used by the Department of Transport (DoT) in Britain, Design Manual HA 48/93, and methods widely used by road authorities in other European countries is based on three levels, i) immediate repairs, ii) problems that do not require immediate attention, iii) no problems. The grading depends upon a subjective judgement of the earthwork condition being made by an experienced engineer. A similar grading is used in the technique being described.

However a more objective criterion for grading earthworks has been developed. The purpose is to avoid the inconsistencies which are likely to arise when different engineers make decisions based on subjective parameters. It is based on the four components which are seen to influence the need for an earthwork to receive attention. The components used are;

i) Hazard, and the danger of road-users being injured or killed.
ii) Earthwork failure risk. Relates to slope collapse or deterioration levels leading to such failure.
iii) The likelihood of disrupting traffic or losing the road if failure does occur.
iv) The relative cost of dealing with any failure.

Hazard is the danger to road users, the social factor, whilst risk is the likelihood of a large scale failure occurring, the engineering factor. Hazard and risk are considered separately and this allows road departments to allocate their own weighting if necessary. Hazard need not be connected with a large earthwork failure and this is taken into account during the earthwork assessment. For example isolated rockfall is dangerous and so is uncontrolled water and debris run-off from slopes, spilling across a road during very heavy rainfall. Failure risk needs to be associated with the inconvenience to road users and the potential repair costs.

Each of the factors is assessed and given a grade 1 to 5 depending upon the level of hazard and risk. So for each earthwork the sum of the hazard and risk criteria is obtained and this is used to assign the earthwork repair priority, based on the three levels described above. For this the database uses a look-up table with weighted factors to divide the 625 values into the three levels allocated to the repair priority.

However a more sophisticated look-up table is also available in the EPMS and this allows earthworks to be divided into ten groups. This can be used for making comparisons about the hazard and risk levels of different highways, or comparing different risk levels and reinstatement work costs. Finally the EPMS allows road authorities to make look-up tables with their own weighted components for hazard and risk criteria and thereby subdivide earthworks into groupings which reflect their own requirements.

At all levels the method of assessment is made as objective as it can be so that it produces consistent results which can be used in grading earthworks for repair.

3.4 Site checks and information reliability:

The information reliability needs to be checked by making visits to earthwork sites and examining problems. Usually these are only carried out on important roads and then only on earthworks which have been classified as requiring urgent attention. It needs to be appreciated that there is no method of ensuring all earthwork problems are identified with the technique being described or any other method. However it does allow tests on information reliability to be carried out and these have been satisfactory. Other methods of earthwork assessment, including inspections on foot generally have no provision for quality checks to be made.

3.5 Dissemination of information:
Following an evaluation of a highway's earthworks the relevant road authority is provided with a comprehensive report outlining the problems, their cause and recommendations concerning their repair. This can be completed within four weeks of a study commencing. A card index containing all of the aerial photographs together with engineering plans and relevant engineering information from the database is also provided, see Figure 1. These cards are useful at meetings with contractors when details of repairs need to be discussed.

Finally there is the earthwork project management database. Earthwork information is organised in three levels, see Figure 2.

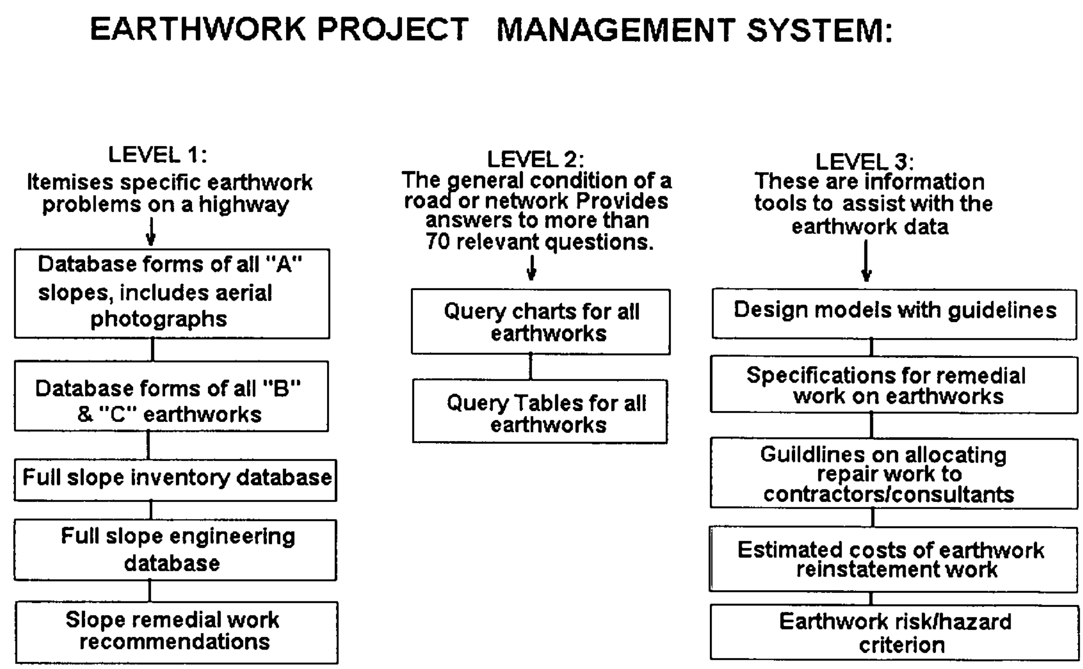

Figure 2. Diagram showing three levels of earthwork information in the database.

3.6 Level one information: Level 1 provides access to general database information and can be used to make decisions about work to be carried out on specific earthworks. Within this level there are five sources of information. The first relates to all earthworks which have been graded as requiring urgent attention. Each of these is shown as a screen panel containing the aerial photograph, a road section diagram, information from the database of inventory and engineer features and recommendations about the remedial action to take. Figure 3 provides an example of the panel. A road network may have up to 500 of these data-panels all of which can be accessed rapidly.

Information for all other earthworks is contained in similar screen panels. However the images are omitted unless there is a specific need. This reduces the demands on computer memory space.

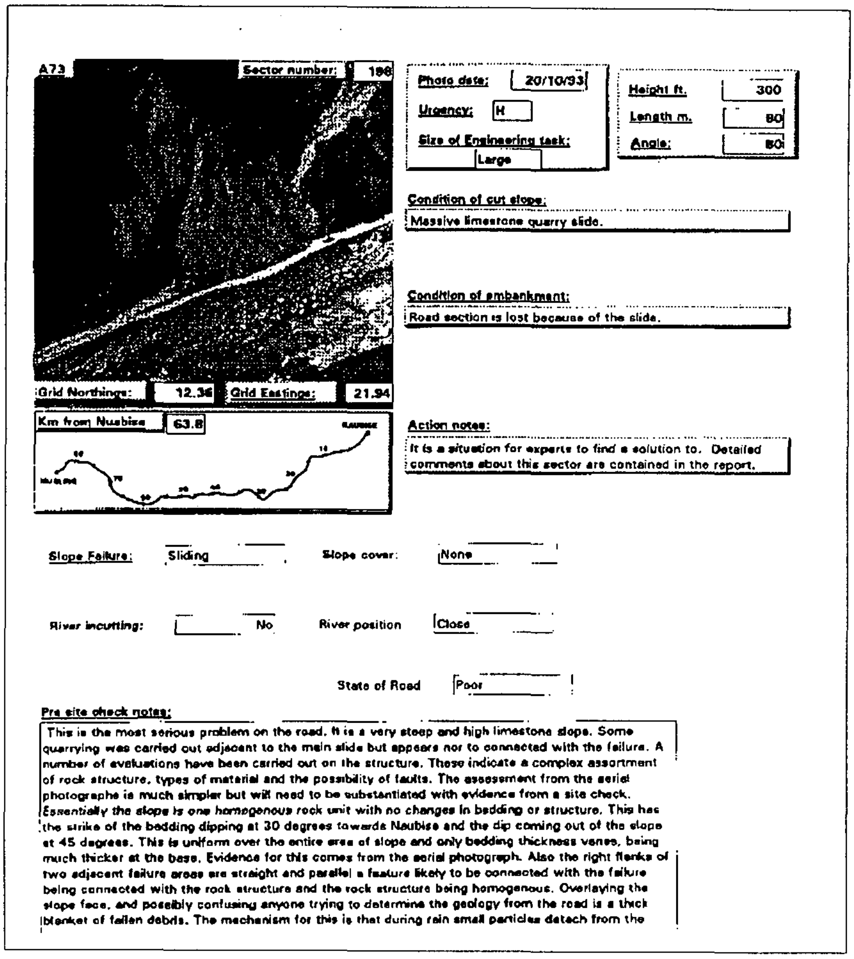

Figure 3. Database information panel for all 'high-priority' earthworks.

Each earthwork has approximately 100 items of information in the database. Not all of this is shown in the panels described above. For a road network of 500 km there is likely to be more than 100,000 items of earthwork information in the inventory and engineering database. Both of these sources can be interrogated by the earthwork project management system user if necessary.

3.6.1 Level two information: The second level is information which is relevant to highway authorities in dealing with road networks and provides information which relates to the overall highway condition. The information consists of storing approximately 70 relevant questions about a road or networks earthwork condition. These are stored as 'queries' in the database which supplies answers to any of the questions when required. Such answers are relevant to many of the policy making decisions within the roads department. Access to these answers can be at a very detailed level, with information in Tables, or at a more general level through colour graphs and charts.

3.6.3 Level three information: There are five areas of support information in the earthwork management system. These are for earthwork design, earthwork remedial work specifications, repair work strategies, repair cost estimates and hazard risk criteria. Each is accessed through an on-screen panel of buttons and performs operations on the relevant earthwork information stored in the database.

Design: Table 1 shows the remedial work tasks for which design methods and specification lists are available or are being added to the database. For example slope angles can be determined using five methods of analysis, which are, empirical charts, equilibrium charts, equilibrium equations, graphical methods and 'software' programs. Each of these methods has at least five analysis options to choose from. All of these design procedures are supported with a description of the method and its limitations.

EQUILIBRIUM SLOPE ANGLES	SEMI-EMPIRICAL SLOPE ANGLES	DRAINAGE BUNDS
CUT-OFF DRAINS	CASCADE DRAINS	BERM DRAINS
SIDE-CHUTE DRAINS	CENTRAL CHUTE DRAINS	ROAD-SIDE DRAINS
SUMP DRAINS	CULVERTS	DISCHARGE DRAINS
CATCH PITS	ADITS	WELLS
WICK DRAINS	MEMBRANE FILTERS	HORIZONTAL DRAINS
GABION SUPPORT WALLS	GABION PROTECTION WALLS	MASONRY SUPPORT WALLS
CANTILEVER WALLS	ANCHOR-PILE WALLS	PILE WALLS
BUTTRESS WALLS	GUNITE	VEGETATION
ROCKNET	ROCK-FALL FENCE	CRIB-WORK

Table 1. Some of the remedial work options for which the database provides results.

Specifications: A similar range of earthwork specifications, with engineering drawings, is available either for road authorities to issue to contractors or as a basis for monitoring contractors work.

Repair work strategy: During the analysis of the aerial photographs the complexity of any engineering repair task is determined and entered into the database. This is subsequently used to provide recommendations to the road authority about how repairs should proceed. Tasks are directed towards small contractors, on a turnkey basis, major contractors, consultants or earthwork specialists. Their allocation is based upon the complexity, the size, the urgency and the hazard risks.

Remedial work costs: The approximate costs of earthwork repairs can be determined from information stored in the database. For this purpose there is a cost equation, of the form shown,

$$\text{Cost} = [\text{PGF}/12 \times (\sum \text{Task}_{1 \text{ to } n}\ 1{,}000.\text{WF})] \qquad \text{Eq. 1.}$$

The EPMS database contains three look-up tables which are used in conjunction with equation 1. The first relates to the problem group factor (PGF) and provides a size for each earthwork task between 1 and 12. The second look-up table itemises the unit cost of each task, the third look-up table provides a weighted factor WF which is based on the effort required to complete each repair task. For example vegetating a slope is considered to cost $(US) 2.5/m^2 (task) in a particular country. The size of the earthwork (PGF) and the work effort (WF) is obtained from information in the database for each earthwork. Costs may then be calculated for a single earthwork, a group or all earthworks.

Risk criteria: Applying a condition criteria to an earthwork has been discussed in section 3.3. The database contains a number of routines for determining risks based upon different criteria.

3.7 The cost of evaluating earthworks:
The cost of collecting earthwork information for 100 km of highway is approximately $ 55/km. This includes the aerial photography and earthwork location information. The overall cost of carrying out a full analysis, producing an inventory and engineering condition database, preparing a report, providing aerial photographs on 'index cards' and the earthwork project management software is $ 140/km. These costs can be significantly reduced when applied to a large network of roads of 500 km or more. The overall costs will also reduce if local staff in road departments undertake some of the work. None of the costs include mobilisation which must be considered separately.

CONCLUSION:

The high cost, complexity and hazard risks associated with highway earthworks makes the use of an earthwork project management system almost essential. The main reason its development has been delayed lies in the difficulty of effectively monitoring earthwork condition at a reasonable cost. The development and testing of a suitable procedure has now overcome such difficulties. It has allowed a considerable amount of experience relating to earthwork failure and repair, which has been accumulated by TRL and many consultants, to be made available to road authorities in a practical way.

ACKNOWLEDGEMENTS:

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REFERENCES:

1) Piteau D.R.& Peckover F.L. (1978) Engineering of rock slopes. Landslide analysis and control. Special report 176. Transport Research Board, Washington DC.

2) Brand E.W. (1984) Landslides in Southeast Asia: A state of the art report. 4th Int.Sym.on Landslides, Toronto.

3) (Heath W.) (1980) Inexpensive Aerial Photography for Highway Engineering & Traffic Studies. Transport & Road Research Laboratory, Report No.632.

4) Heath, Nik Ramlan & Shaffie (1992) Highway Earthwork and Slope Assessment in Malaysia. 7th Conf. Road Engineering Assoc. of Asia & Australia. 22-26

June 92, Singapore.